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with Electronics Supplement

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Volume XVI

INTERAVIA

June 1961

WORLD REVIEW OF AVIATION AND ASTRONAUTICS

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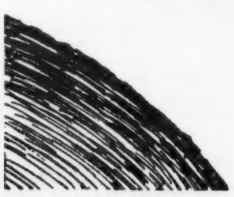

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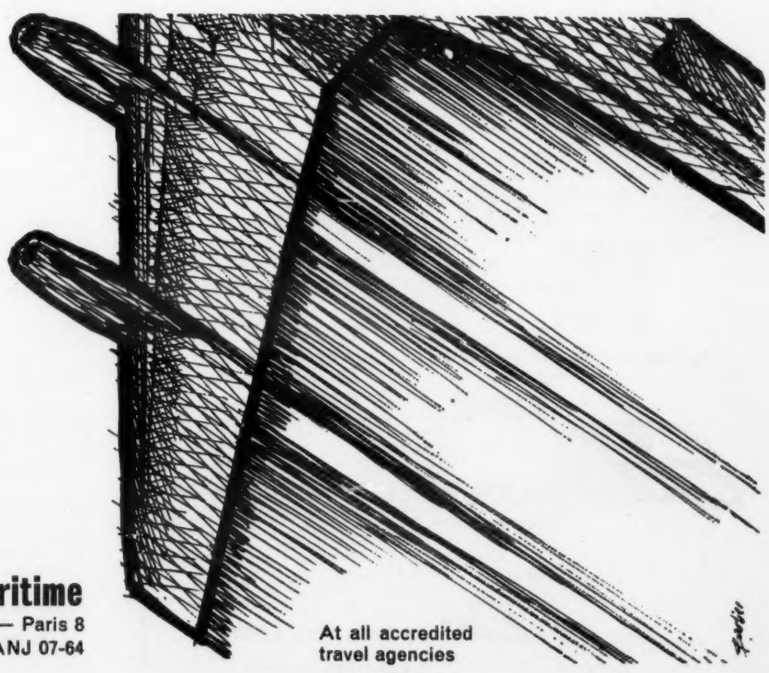

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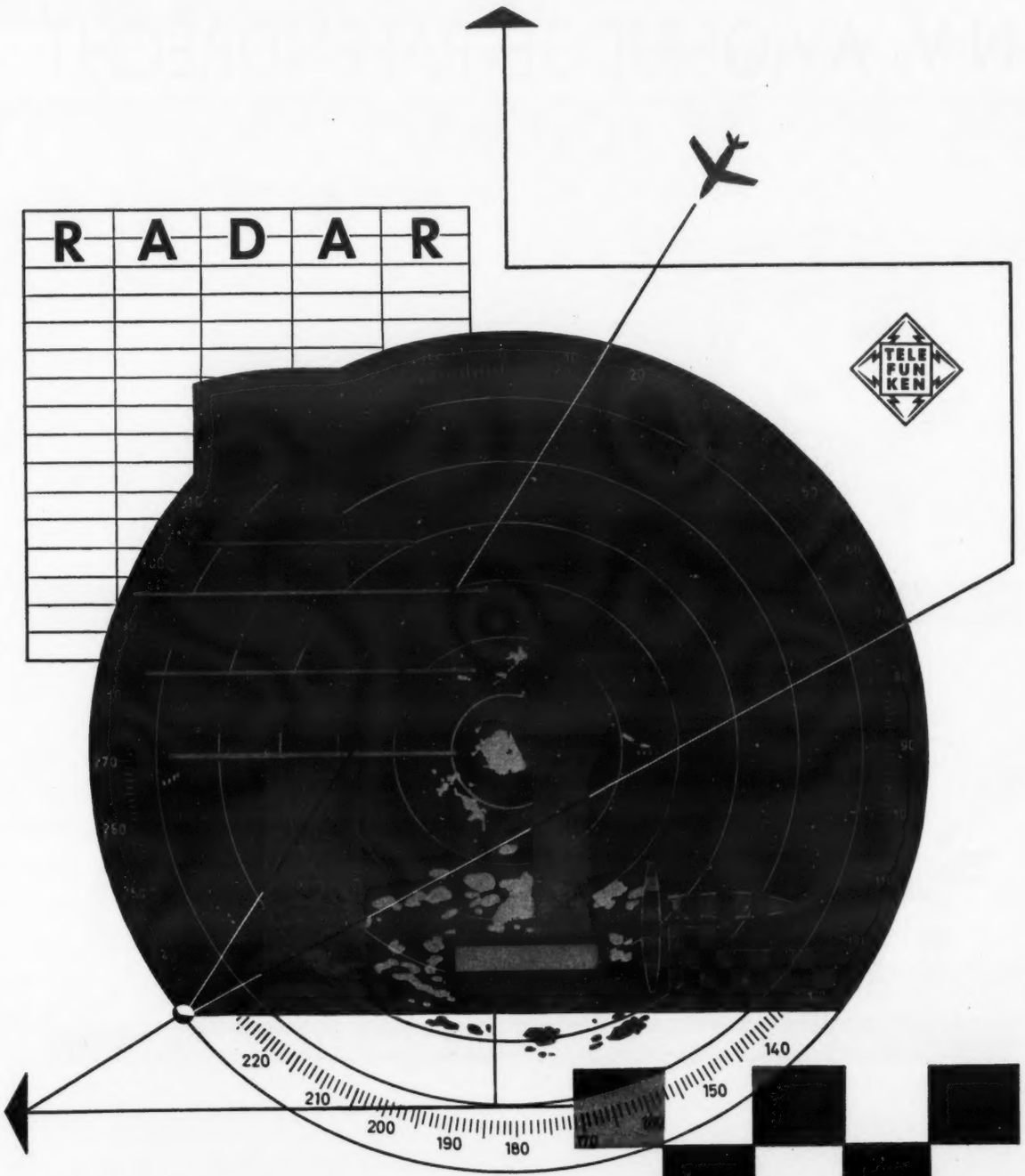

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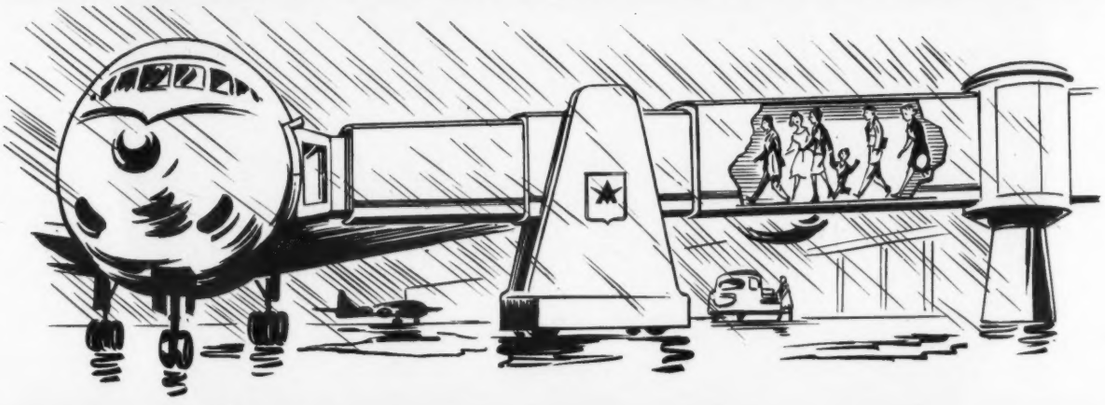

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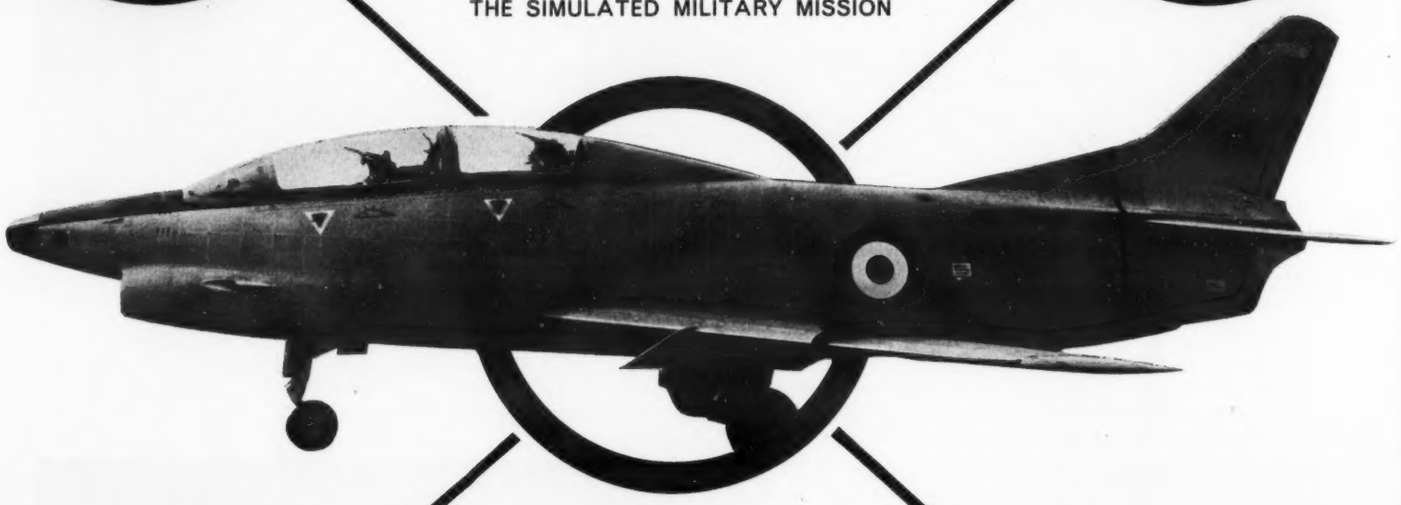

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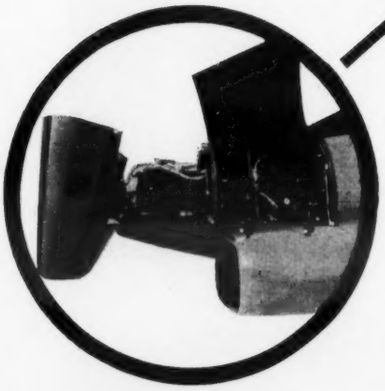
RETAINS THE MAIN CHARACTERISTICS AND PERFORMANCE OF THE SINGLE-SEAT FIGHTER AND CAN HENCE BE USED AS AN OPERATIONAL TACTICAL LIGHTWEIGHT STRIKE AIRCRAFT



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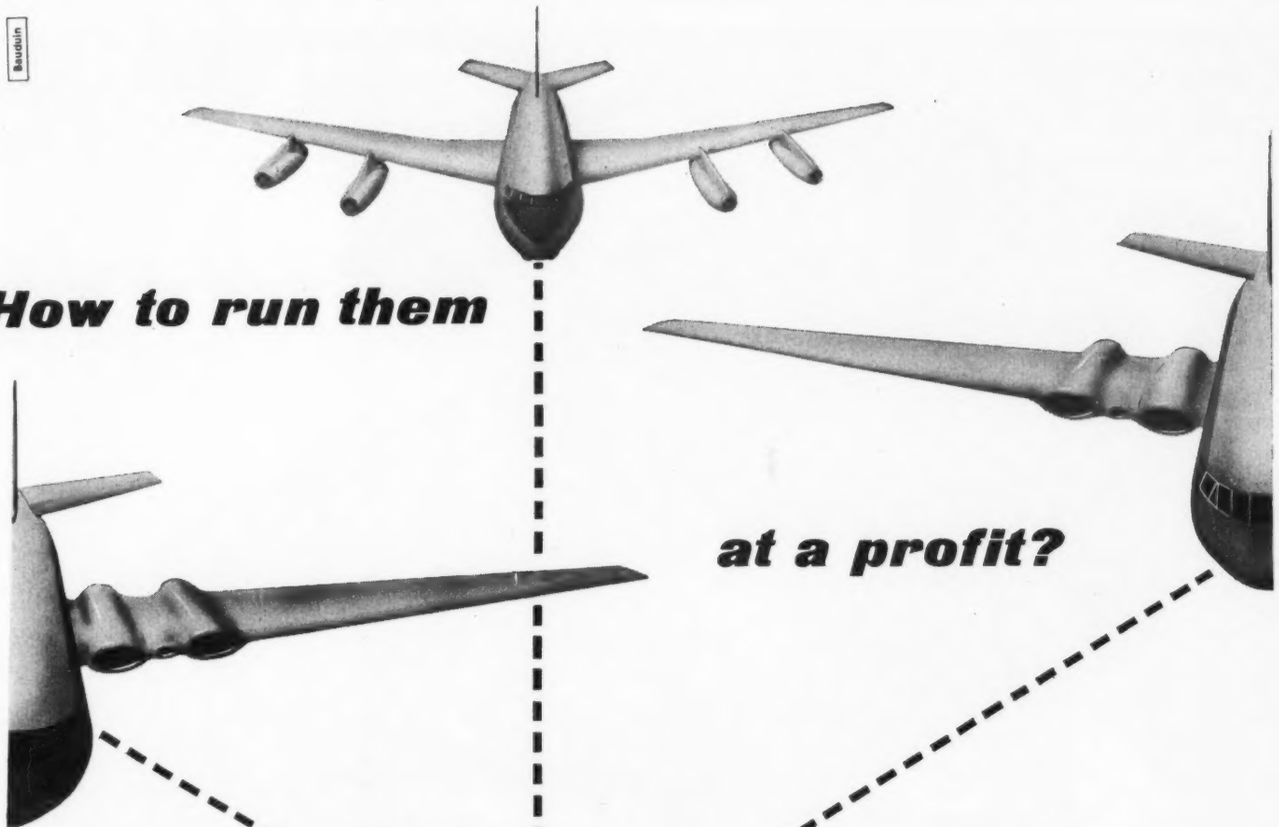

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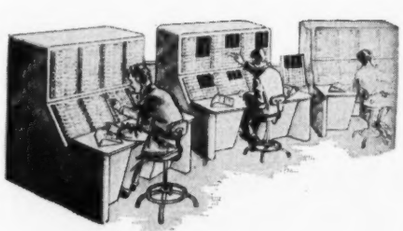

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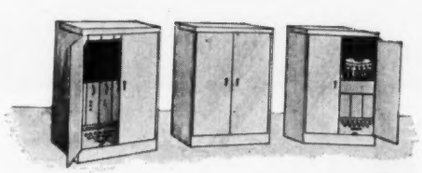

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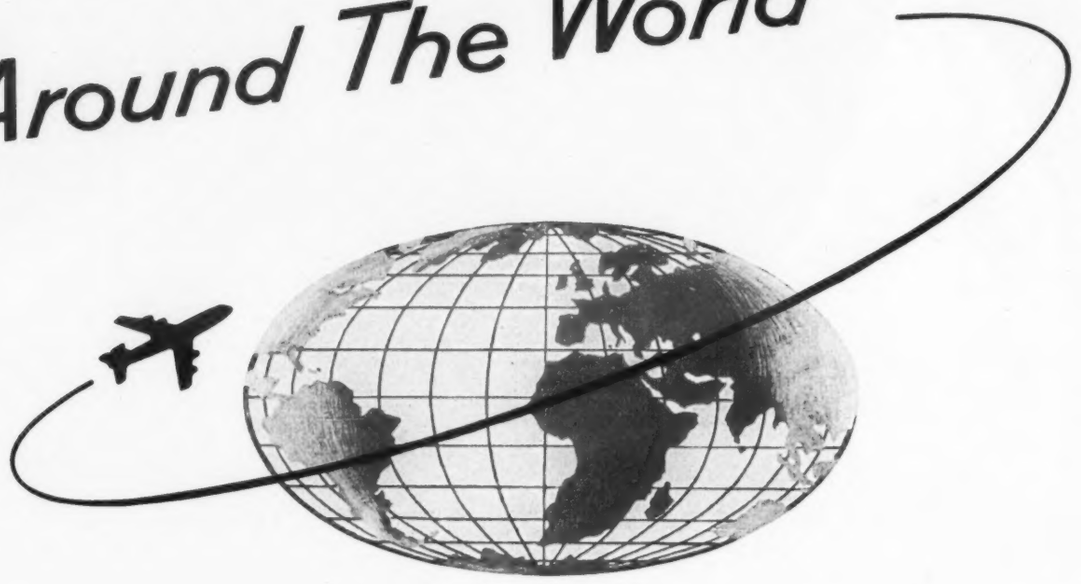

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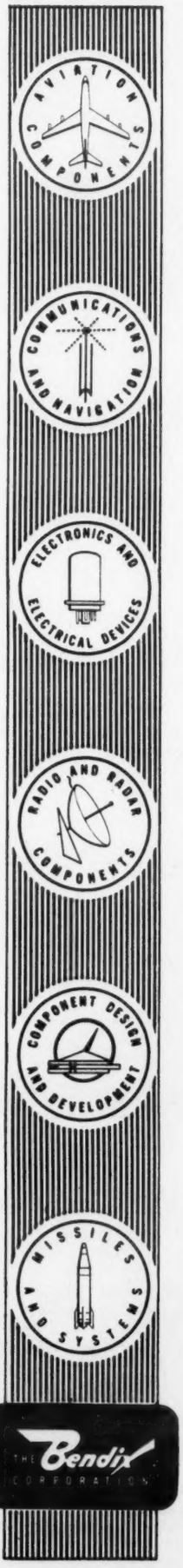

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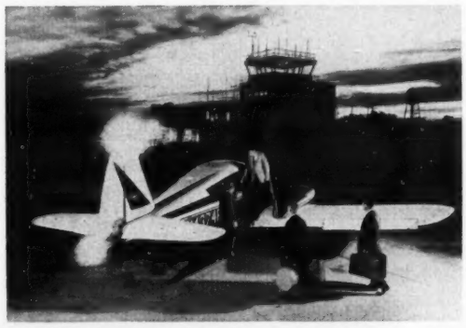

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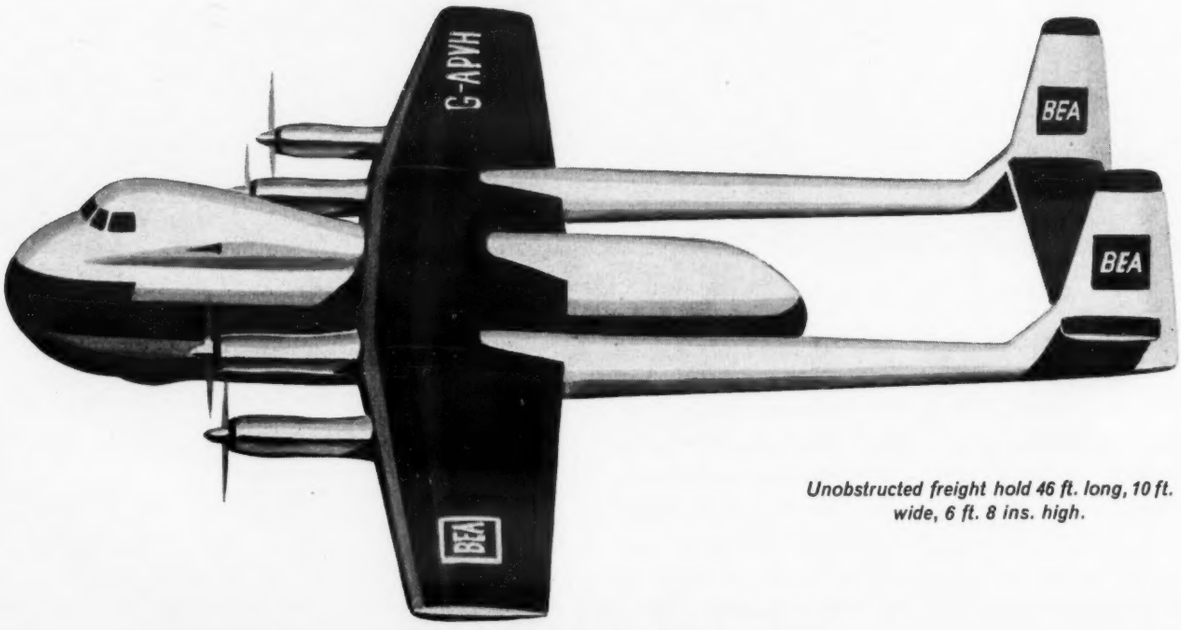

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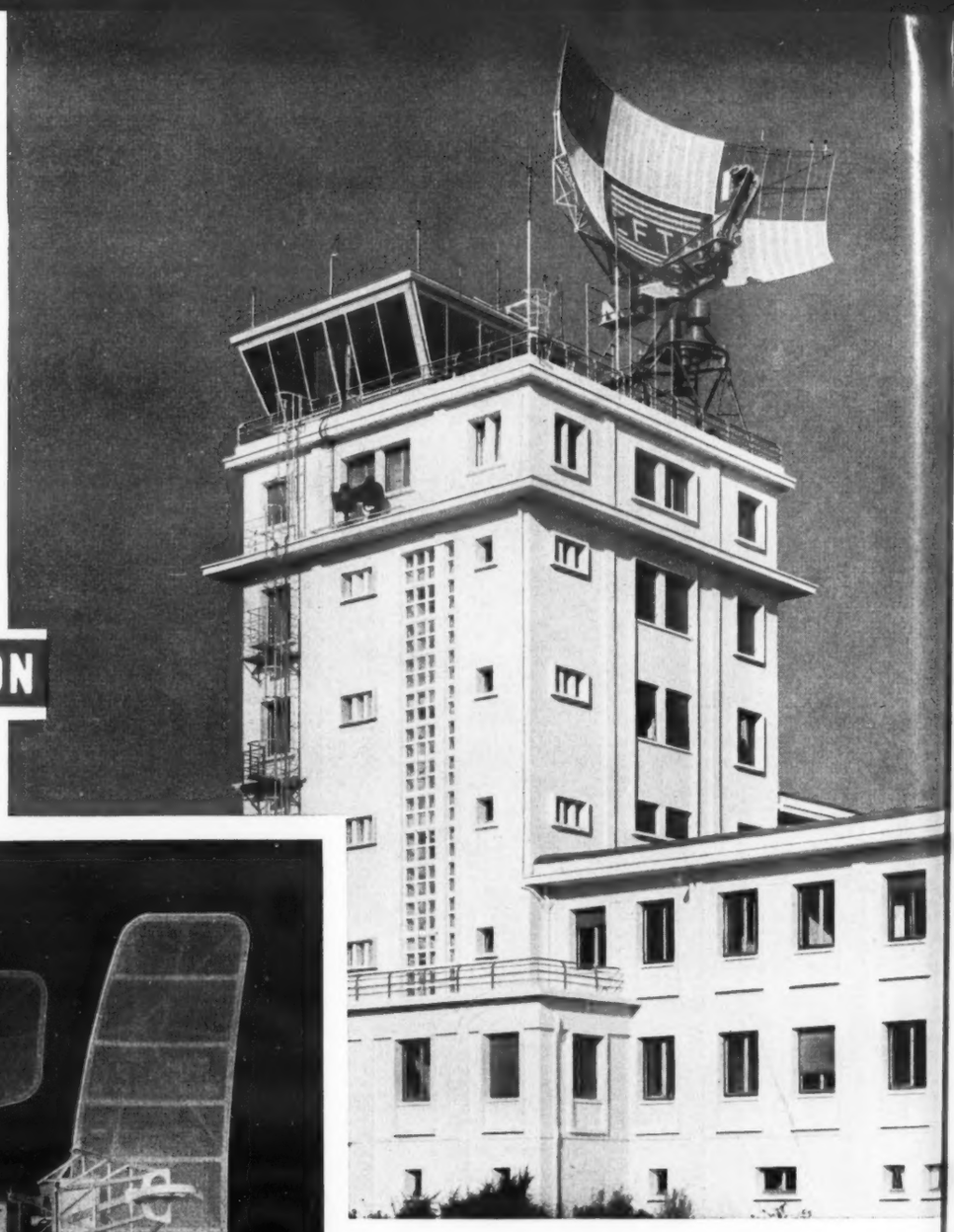

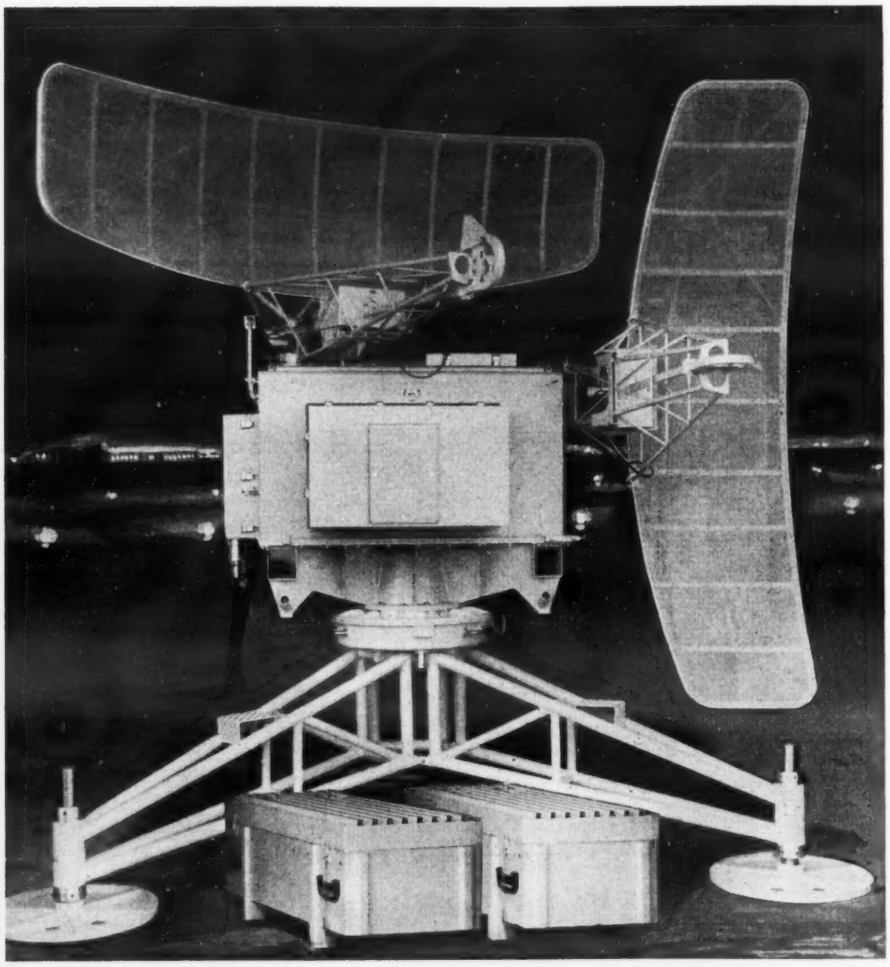

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The eighteen IATA member airlines working the North Atlantic route operated a total 6,080 scheduled flights (east and westbound) in first quarter 1961, an increase of 4.2 percent over the same period in 1959 (first class nil, economy class 372, mixed 4,755 and cargo 953). Continuing introduction of large jets put seating capacity up 46.9 percent, with an increase of only 1.4 percent in the actual number of flights. Over 83 percent of passenger traffic was in the economy class. Scheduled all-cargo flights were up by 23 percent. The results were :

	Seating capacity	Revenue passengers	% seats utilized
First	132,439	48,626	36.7
Economy	457,235	245,049	53.6
1st quarter total	589,674	293,675	49.8
Percent. over 1960	+46.9	+28.8	— 7.0

Cargo and mail volumes recorded on North Atlantic passenger and cargo flights during the quarter were :

	Cargo (kg)	Mail (kg)
Passenger	7,156,952	3,042,549
Cargo	6,338,772	1,501,148
Total	13,495,991	4,543,697
Variation	+34.0	+45.6

●

Japan and the United States were due to start talks in Washington on May 29th on a requested New York route for Japan Air Lines. The Japanese Government originally applied in March and informal negotiations have already been held. JAL currently operates to U.S. West Coast points only and approval of a route to New York would be another step in the carrier's proposed round-the-world route.

●

British Overseas Airways Corporation inaugurated daily Boeing 707 service to Washington (Baltimore Friendship) on June 1st. Flight 511 operates London-Boston-Washington every Tuesday, Thursday and Saturday. Flight 501 operates via New York on the other days.

●

Pan American World Airways inaugurated first jet service to Costa Rica with Douglas DC-8s on June 4th. PanAm schedules four flights a week between Houston and San José (Costa Rica) via Mexico City and Guatemala, and four flights a week between Panama and San José.

●

Qantas will operate twice-weekly Sydney-Johannesburg service in July, cutting the present 24-hour stopover at Mauritius to a one-hour refuelling stop. The carrier will station a crew full time at Mauritius. Departures Sydney each Saturday and Johannesburg each Monday. The South African Airways' service will depart Johannesburg alternate Fridays and Perth alternate Mondays.

●

United Arab Airlines will take delivery of its fourth and fifth de Havilland *Comet 4 Cs* on June 15th and August 15th to consolidate existing routes. UAA future planning includes daily service to London effective August 1st and inauguration of further services to Madrid, Moscow, Prague, Karachi and Bombay. Three Douglas DC-6Bs recently bought from SAS are now in operation on UAA's Syrian Region network.

●

Ernst H. van der Beugel took over as President of KLM Royal Dutch Airlines on June 1st, succeeding Izaak A. Aler who has retired. Van der Beugel is only KLM's third President since formation of the company in 1919.

●

West German postal authorities hope to introduce scheduled night airmail service in July operating Hamburg-Frankfurt-Hamburg, Bremen-Düsseldorf-Frankfurt and return, Hanover-Cologne-Frankfurt-Hanover, Munich-Frankfurt and return and Nuremberg-Stuttgart-Frankfurt and return. Frankfurt am Main will be the focal point of the night mail service and is expected to handle some 20-25 tonnes of letter post each night. Scheduling will bring all aircraft back to terminal points by 03:00 hours to facilitate early mail deliveries. Surface mail will be handled by air without surcharge.

●

Sabena is expected to report a deficit of Bfr 130 million ($2.6m) for the 1960 year. The carrier had a deficit of Bfr 197.6 million ($3.95m) in 1959.

Industry

West German Defence Minister Strauss favours the establishment of a Federal Agency to coordinate air and space research, controlled by either the Ministry of Transport or the Ministry for the Interior. Official responsibility for aviation matters is extremely widely scattered in Germany and a coordinating body would clearly avoid further decentralization and promote international cooperation.

●

Bölkow Entwicklungen KG has laid down an initial production batch of 150 F-207 four-seat business and touring aircraft (a development of the Klemm 107) and work on this first series will carry through to end-1962. The bulk of the 1961 production has already been sold and a second run of 100 aircraft appears likely.

●

Sud-Aviation now has orders for a total 39 *Alouette II* helicopters for Belgium. The French Government order has been increased to 365 and civil orders for the home and export market total 410. Total order book at mid-May was 775.

Bombrini Parodi-Delfino is expected to take a financial interest (probably through its Aerochemie subsidiary) in the Italian SIS-PRE company, currently controlled by Finmeccanica and Fiat. In addition to the production of multi-stage meteorological sounding rockets, BPD will also probably participate in Fiat's Divisione Mare production programme for the Bölkow 810 *Cobra* surface-to-surface missile.

●

Marconi's Wireless Telegraph Company has an Admiralty contract to supply and install a type S 264A/H 500 kW, 50-cm radar at the Royal Naval Air Station, Yeovilton (Somerset). The contract includes five SD 1020 fixed-coil display units and a video map.

●

Pye Telecommunications Ltd. has a Polish Government order to supply an ILS for installation at Warsaw-Okecia International Airport. This is Pye's first Polish order but 13 ILS have been supplied to Eastern European airports.

●

General Electric's Heavy Military Electronics Department has received a $36 million U.S. Navy contract for production of the new AN/SPS-30 long-range height-finding radar for installation on modern missile cruisers and U.S. fleet carriers. First delivery is scheduled for May 1962 to replace GE-built AN/SPS-8 radars now in service on many U.S. Navy ships. A mechanically-stabilized antenna compensates for ship roll and pitch, and the equipment gives simultaneous determination of direction range and height of multiple airborne targets. Tests were carried out aboard USS *Macon* last summer.

●

Republic Aviation's Paris office reports significant progress in cooperation with Fokker in the further development of a VTOL strike/reconnaissance fighter to meet NATO requirements. Republic, Fokker and Bristol Siddeley Engines are now working on the second phase of development. Fokker recently sent a group of scientists and engineers to the U.S. to evaluate Republic and NASA advances in the areas of variable geometry wings and supersonic ducts. Republic is working with Fokker on an engine/airframe optimization study utilizing advanced engines of the Bristol BS. 52 type under a U.S.-Netherlands Government financed programme.

●

Douglas Aircraft Co. has an Air Force order to supply 22 more *Thor* rocket vehicles for use in satellite booster missions. The model DM-21 incorporates a shorter, lighter airframe than the missile version and is powered by an uprated 165,000-lb thrust Rocketdyne engine. No dollar value has been disclosed but the new contract will extend *Thor* production up to end-1962.

The E. E. Heiman Prize, 1961

The three prizes, totalling $3,000, in this international essay competition set up by *Interavia* in memory of its Founder and Editor-in-Chief, E. E. Heiman, were awarded on May 31st, on the occasion of the Paris Air Show. The Panel of Adjudicators met in a private room at the Restaurant Drouant in Paris, under the chairmanship of Paul Moroni, Secretary General of Civil and Commercial Aviation, Paris.

The first prize of $1500 was awarded to Dr. Erwin Skubinna, Helmut Brusberg and Manfred John, all of Stuttgart, Germany, for a jointly submitted essay. The second prize of $1,000 was won by J. F. Wildhaber of Lucerne, Switzerland, and the third prize of $500 went to Raymond Nivet (Air France), who was also a prizewinner two years ago.

* Interavia Air Letter is a daily international news digest published in English, French ("Courrier Aérien") and German ("Luft-Post"). All rights reserved.

NASA has given The Martin Company a $75,000 contract to study earth-moon transportation systems capable of 1) landing three men on the moon and returning immediately to earth, 2) supporting three men on the moon for 30 days, and 3) supporting a permanent moon station with a complement of 10 to 12 men. The contract calls for consideration of all phases of rocket vehicle operation to support the three missions. Martin is one of three space companies which recently completed similar $250,000 feasibility studies on *Apollo*, the manned vehicle which it is hoped will carry three men in wide orbit around the moon.

Military Affairs

The Bundestag Budget Committee has approved procurement of a further 124 Sud-Aviation *Alouette* helicopters for the West German Army, and 24 Fiat G.91 trainers (to be built in Italy). Also approved are two Convair CV 440 *Metropolitans* and three Dornier Do 28s for the Army. West German procurement of additional Lockheed F-104 *Starfighters* to be built in the U.S. is believed to cover a batch of 50-60 F-104F trainers. The new order will reportedly have no effect on the European programme for the construction of 949 aircraft. An official West German contract for the *Pershing* missile is expected shortly.

●

Air Minister Senator Harrie Wade has announced official selection of the SNECMA *Atar 9* to power the 30 *Mirage IIIs* for the Royal Australian Air Force, in preference to the Rolls-Royce *Avon*. Australian *Mirages* will have either the original *Atar 9C* or the more powerful *9K* model now under test by the French Air Force (final decision early September). Production will be under licence by Commonwealth Aircraft Corporation.

●

U.S. Army has selected the Bell D-250 and the Hiller 1100 as winners of its light observation helicopter design competition and each company is to build seven prototypes for user tests at Fort Rucker, Ala. in mid-1962. Production contractors will be selected by mid-1963. Requirement will probably total 4,000 aircraft (480 a year) at a total cost of $200 million. The Army's new LOH will be powered by Allison T63 turboshaft engines and will feature a single foldable rotor allowing four aircraft to be transported aboard a C-130 transport. Gross weight 2,400 lb; cruising speed 110 knots; capacity four seats or pilot plus fuel and 400-lb payload.

●

U.S.Navy plans to request funds in 1962 to start development of a new seaplane, most probably for ASW tasks. Chief of Naval Operations Admiral Arleigh Burke has told the House Armed Services Committee that it is hoped to start R&D next year. The last production line seaplane was the Martin P5M, still in use but rapidly becoming obsolescent.

●

U.S. Navy has given Autonetics Division of North American Aviation Inc. a $21 million contract to manufacture Ship Inertial Navigation Systems (*SINS*) for nine Lafayette-class *Polaris* ballistic missile submarines. Tailored for the 2,500 n.m. A-3 *Polaris*, the Lafayette class will have an overall length of 425 feet and a displacement of 7,000 tons.

Aircraft and Powerplants

British Aircraft Corp. has released the following technical data for the new *BAC. 111* short-haul airliner, first orders for which have already been booked. Powerplant two Rolls-Royce RB. 163-1 *Spey* by-pass jet engines of 9,850 lb guaranteed minimum take-off thrust at sea-level. Span 88 ft 6 in.; overall length 93 ft 8 in.; wing area 980 sq. ft; aspect ratio 8; wing sweep 20° at 25 % chord. Maximum ramp weight 66,300 lb; maximum take-off weight 66,000 lb; maximum take-off weight 66,000 lb; maximum landing weight 62,500 lb ; maximum zero fuel weight 56,000 lb; design maximum payload 14,000 lb. First prototype flight is expected spring 1963 with airline deliveries commencing August 1964. Maximum capacity is 69 passengers or mixed-class cabin layout for 57 passengers. Economic cruise speed approximately 430 knots. Maximum cruise speed 470 knots at 25,000-30,000 ft. Full complement of 57 mixed-class passengers and baggage can be carried at 430 knots over stages of up to 800 miles, with 2 hours' reserve.

●

Rolls-Royce has five RB. 163-1 *Spey* development engines running and some 250 hours bench testing has already been completed. The *Spey* has been selected to power the DH. 121 *Trident* passenger transport and the new *BAC. 111* and the British company has a Ministry of Aviation development contract for a military version. Minimum guaranteed sea-level take-off thrust is 9,850 lb; typical cruise consumption 0.766 lb/lb.t/h at 25,000 ft ISA and Mach 0.78; basic dry weight 2,200 lb; length 110 in. from intake face to exhaust cone flange; maximum diameter 37 in.

●

Italian engineer Sergio Stefanutti has drawn up a project for a V/STOL tactical transport designated Ce.Co.S.3 (Centro Consultivo Studi e Ricerche—a Defence Ministry department; S = Stefanutti). The aircraft, which is being entered for the NATO design competition, will have four swivelling propellers, all working in the horizontal position for take-off and hovering. Two propellers in the vertical position will supply sufficient propulsive power to give an average speed of 330 m.p.h.

●

Hispano Aviación is developing a twin-jet business aircraft designated HA. 230 *Seata Voyager*. Powerplant will be two Turboméca *Marboré IIs* and cabin layout will be for four-six passengers.

●

Aero Commander Inc. has announced the new model 1121 twin-jet business aircraft with a pressurized cabin for pilot and five passengers. Take-off weight 14,000 lb with 6,500-lb payload. Powerplant two General Electric CJ-610-1 jet engines of 2,700 lb thrust each. Range 1,500 miles at Mach 0.8 and 20,000 ft. First flight of the prototype is scheduled for autumn 1962.

●

The IA-38 flying wing freighter built by the State-owned DINFIA concern has now reportedly entered flight testing. The IA-38 has four 450 h.p. IA-16 radial engines driving pusher propellers.

●

Reports from Buenos Aires indicate that the Turbay T-3 small twin-engine transport will begin flight testing in the near future. The T-3, with accommodation for seven passengers or equivalent freight, is powered by two 180 h.p. Lycoming engines.

●

The Latécoère company of France is working on three turboprop aircraft projects. The 8-seat *model 870* business aircraft is powered by two 550 s.h.p. Turboméca *Astazou IIs*. Span 39.37 ft; length 38.71 ft; wing area 161.5 sq.ft; take-off weight 7,520 lb; maximum cruising speed at 16,500 ft is 360 m.p.h.; service ceiling 39,370 ft. The *model 863* is designed for transporting 38 passengers or 9,920 lb of freight, and is powered by four 930 s.h.p. Turboméca *Bastan IVs*. Utilization for night mail transport and day passenger services with the installation of palletized seats (a swing-tail pure freight version of this aircraft is also planned). Span 78.74 ft; length 69.05 ft; wing area 646 sq.ft; take-off weight 31,085 lb ; cruising speed 372 m.p.h. at 16,400 ft ; service ceiling 36,090 ft. The third aircraft is the *model 853* freighter with two Turboméca *Astazous*. No further details are currently available.

●

The following data has become available for the new Saab 105 multi-purpose five-seat trainer which is powered by two Turboméca ducted fan engines each of 700 kp (1,540 lb) thrust ; Span 9.5 m (31.17 ft) ; length 10.5 m (34.45 ft) ; wing area 16.3 m² (175 sq. ft) ; weight empty 2,000 kg (4,410 lb) ; maximum take-off weight 3,700 kg (8,160 lb) ; tank capacity 1,400 l (310 Imp. Gal) ; maximum range at 11,000 miles (36,090 km) altitude and at 650 km/h (400 mph), 2,700 km (1,680 miles) ; ceiling 13,000 m (42,650 ft) with rate of climb 0.5 m/sec (100 fpm) ; rate of climb at sea level 24 m/sec (4,720 fpm) ; take-off distance over 15 m (50 ft) obstacle 610 km (2,000 ft). The sales price as quoted by Saab is in the region of $200,000.

●

Upstart is the designation of a new target missile with rocket propulsion system produced by Aeronca Manufacturing Corp. It is launched vertically, in the same way as Aeronca's *Pogo-Hi*, can reach altitudes of over 30,000 m (100,000 ft) and land by parachute. Recently the Army launched a first *Upstart* at White Sands Missile Range. Information about the missile is not yet available.

●

As at May 17th, 1961 the United States had put 39 satellites into earth orbit, and the Soviet Union 12. Both the United States and the Soviet Union have each put two planetoids into solar orbit. Satellites and space probes still in orbit as at May 17th were:

Name	Country	Launched	Transmitting
Explorer 1	USA	31. 1.58	No
Vanguard 1	USA	17. 3.58	Yes
Lunik 1 *	USSR	2. 1.59	No
Vanguard 2	USA	17. 2.59	No
Pioneer 4 *	USA	3. 3.59	No
Explorer 6	USA	7. 8.59	No
Vanguard 3	USA	18. 9.59	No
Explorer 7	USA	13.10.59	Yes
Pioneer 5 *	USA	11. 3.60	No
Tiros 1	USA	1. 4.60	Yes
Transit 1B	USA	13. 4.60	No
Space Vehicle 1	USSR	15. 5.60	No
Midas 2	USA	24. 5.60	Yes
Transit 2A	USA	22. 6.60	Yes
Radiation 1 (NRL)	USA	22. 6.60	No
Echo 1	USA	12. 8.60	No
Courier 1B	USA	4.10.60	Yes
Explorer 8	USA	3.11.60	No
Tiros 2	USA	23.11.60	Yes
Samos 2	USA	31. 1.61	No
Venus Probe	USSR	12. 2.61	No
Explorer 9	USA	16. 2.61	No
Discoverer 20	USA	17. 2.61	No
Discoverer 21	USA	18. 2.61	No
Explorer 10	USA	25. 3.61	No
Discoverer 23	USA	8. 4.61	No
Explorer 11	USA	27. 4.61	Yes

* In solar orbit, others in earth orbit.

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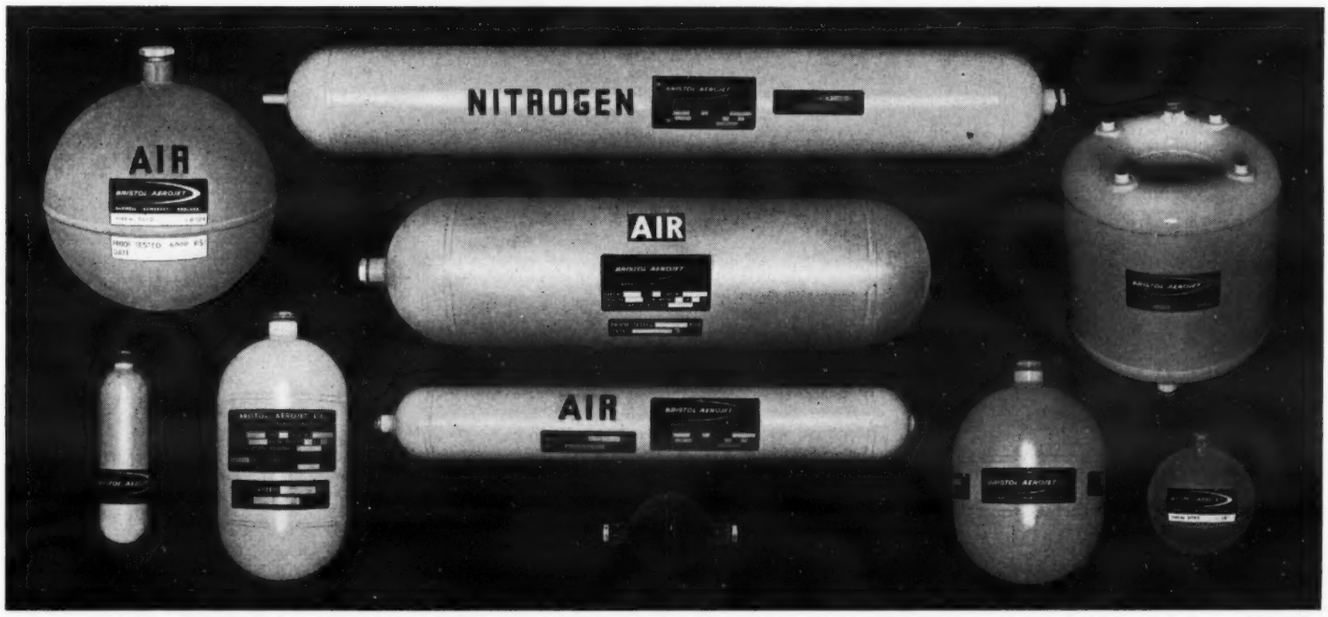
PERFORMANCE PAYLOAD PROFITS UP



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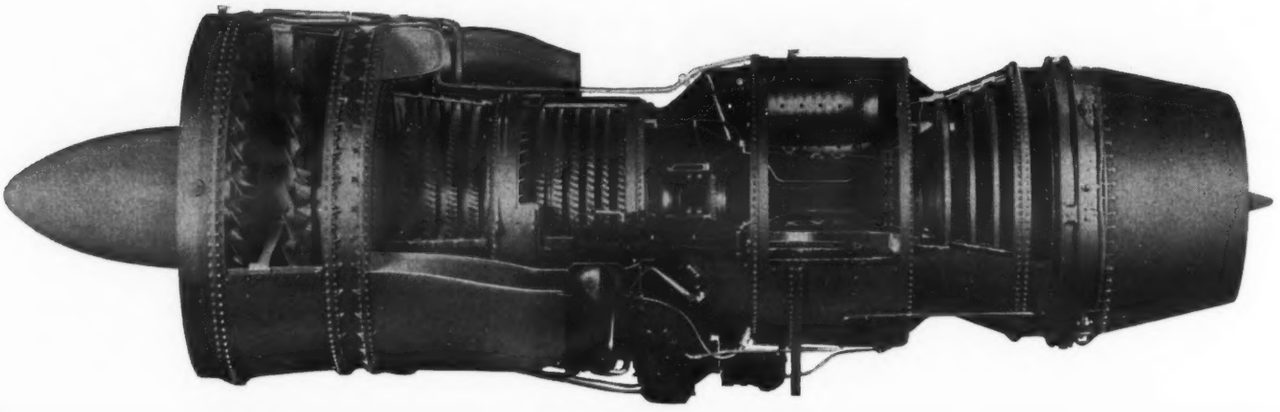

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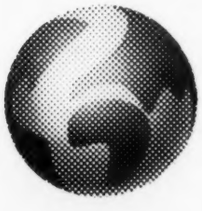

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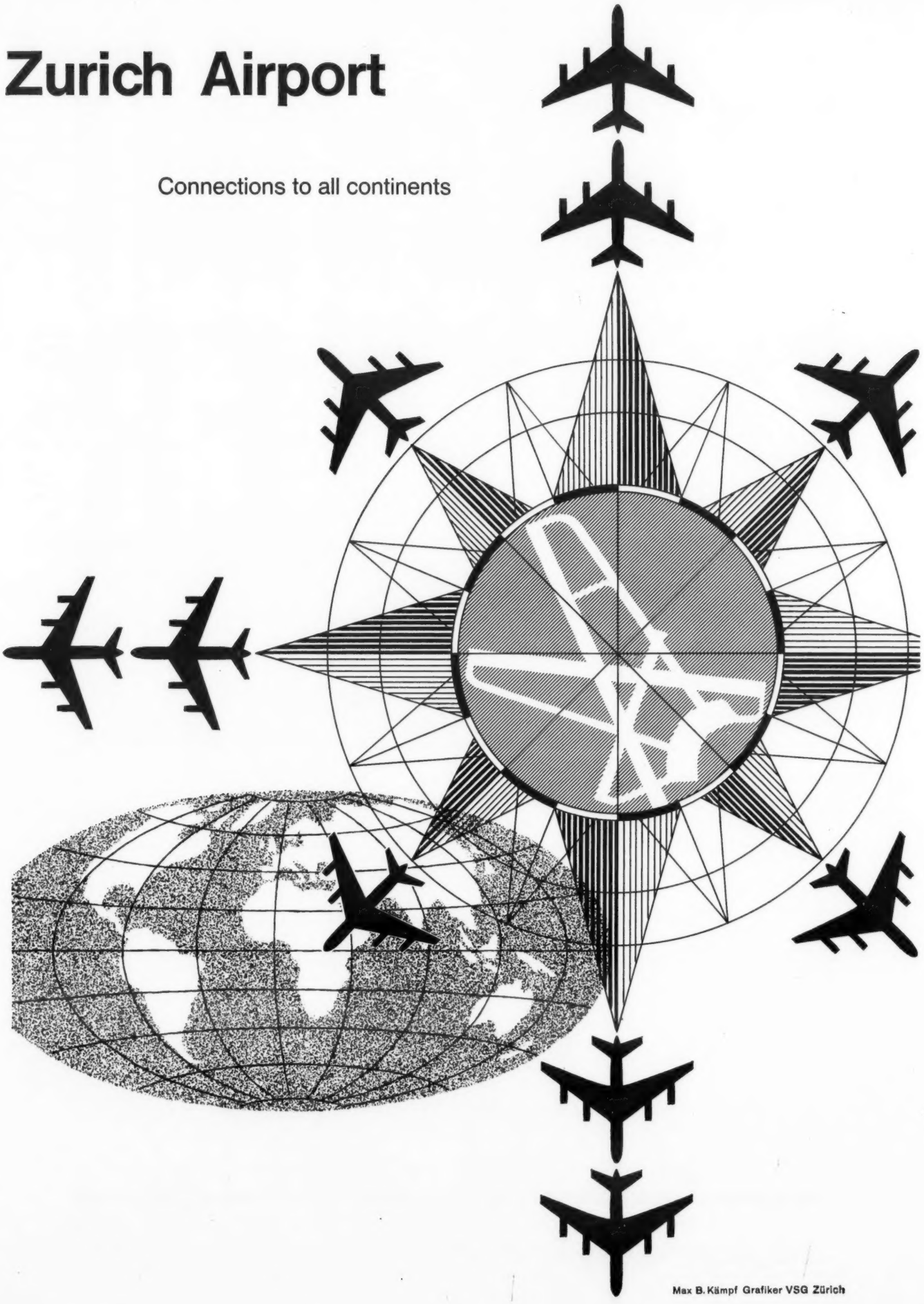

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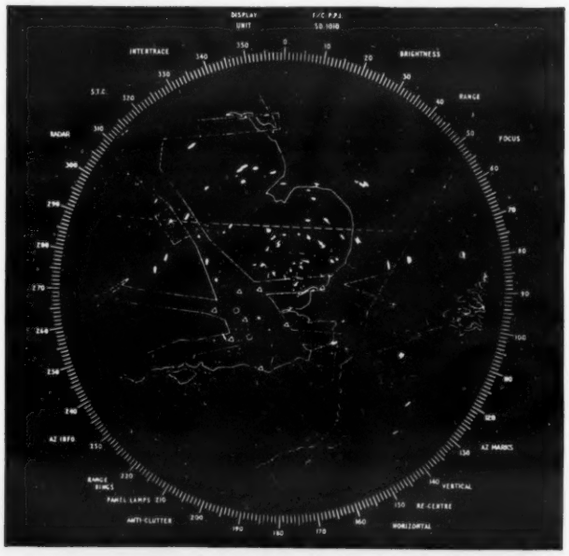

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POLARIS—Hughes is a prime contractor for the production of complete guidance systems for the Navy's sub-launched ballistic missile and is a subcontractor for the fire control system.

SIDEWINDER—This Navy air-to-air missile will carry Hughes infrared detector and cryostat systems in its most advanced models.

TITAN—Hughes is manufacturing portions of the launch control systems for this Air Force giant.

MAULER—A highly mobile anti-aircraft and anti-missile missile being developed for the Army, the Mauler will have a Hughes designed guidance system.

Hughes is also under contract to investigate the application of Versatile Automatic Test Equipment (VATE) for the guidance systems on the *MINUTEMAN, SKYBOLT, ATLAS, TITAN* and *HOUND DOG* missiles.

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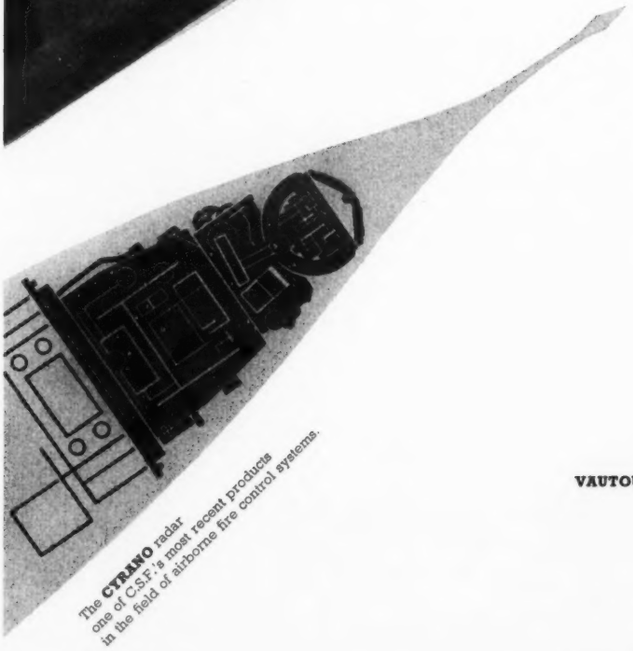

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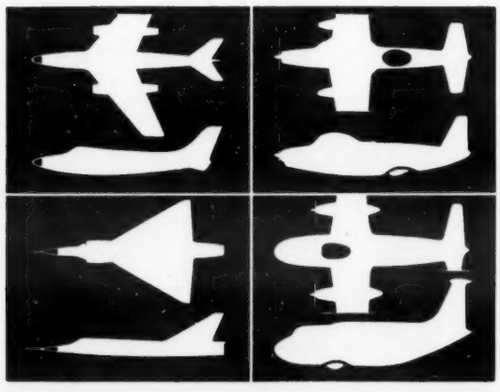

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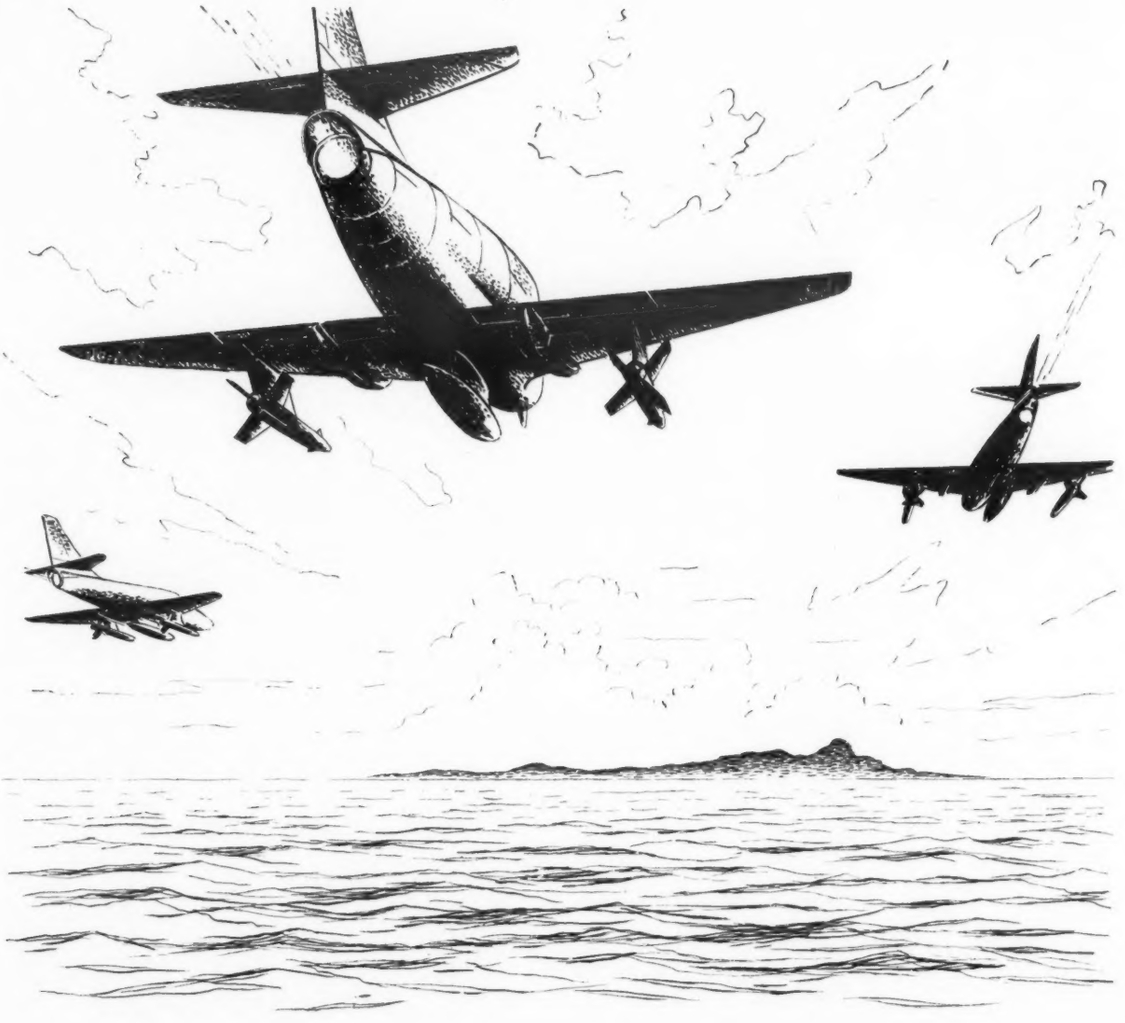

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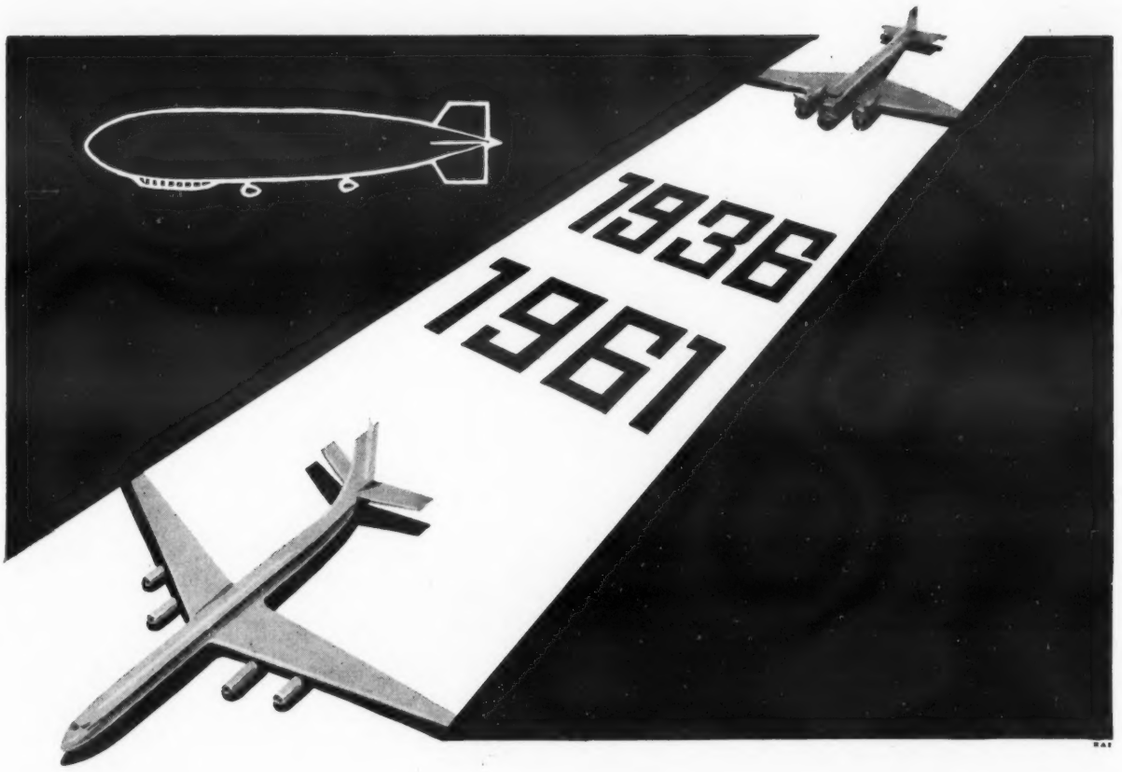

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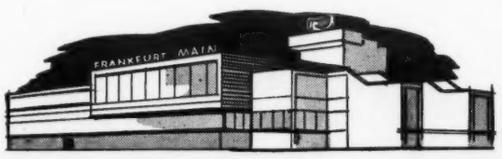
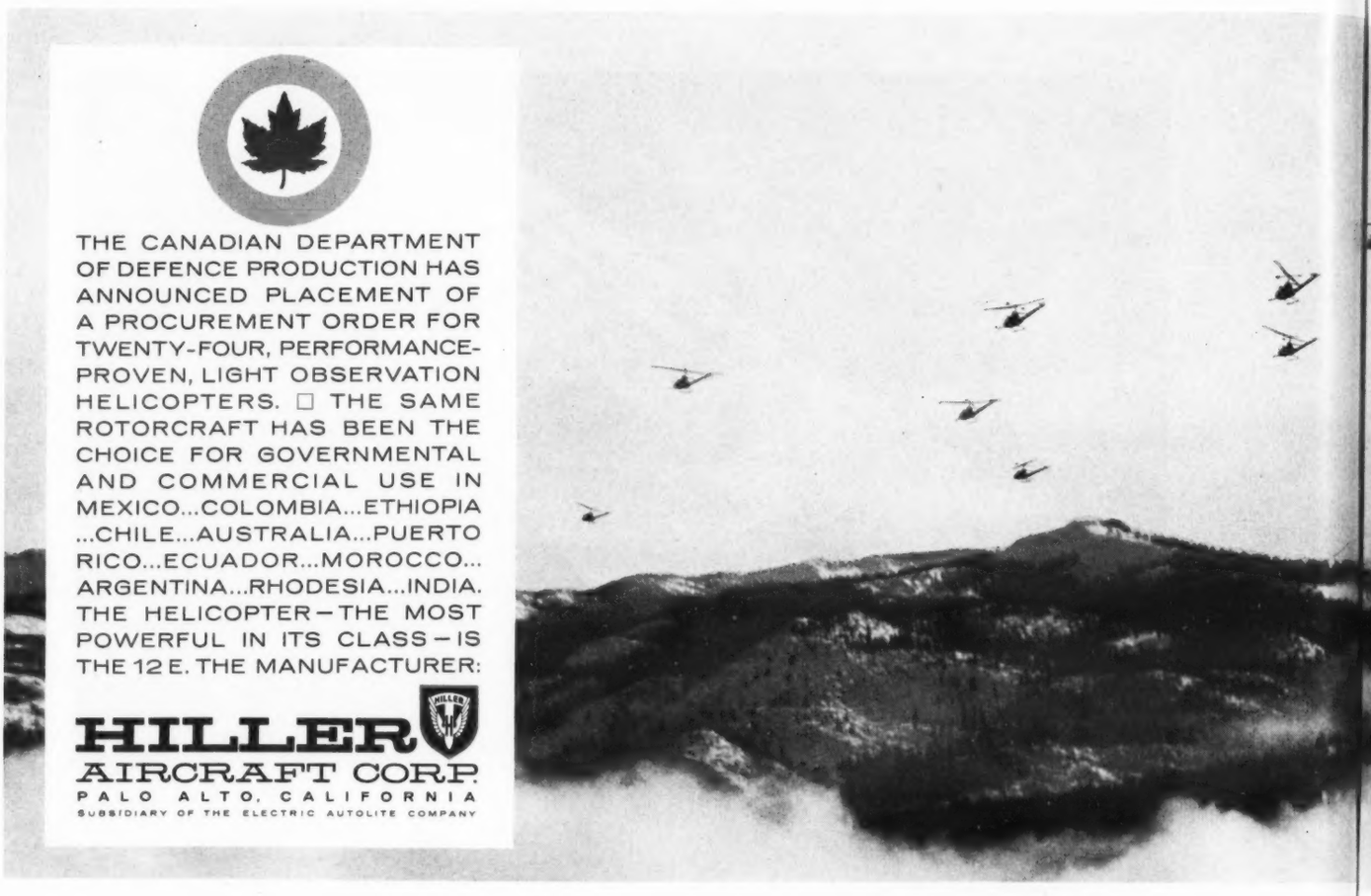


Flughafen Frankfurt/Main Aktiengesellschaft



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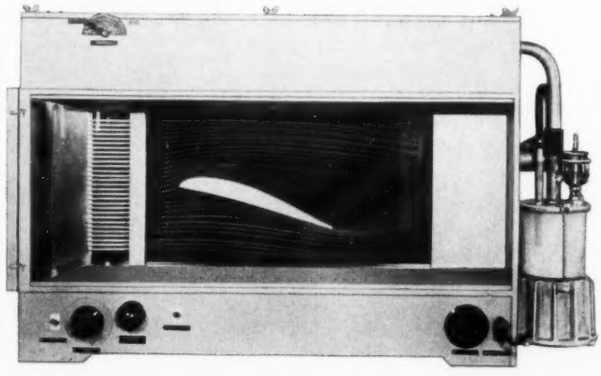

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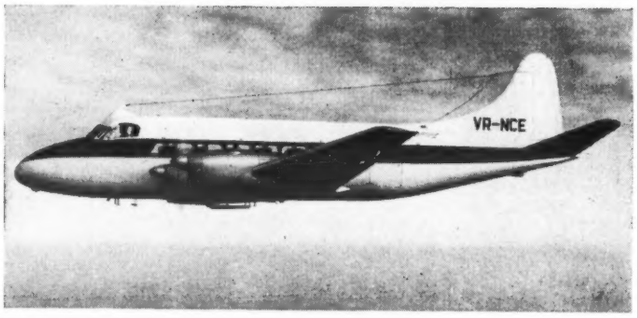

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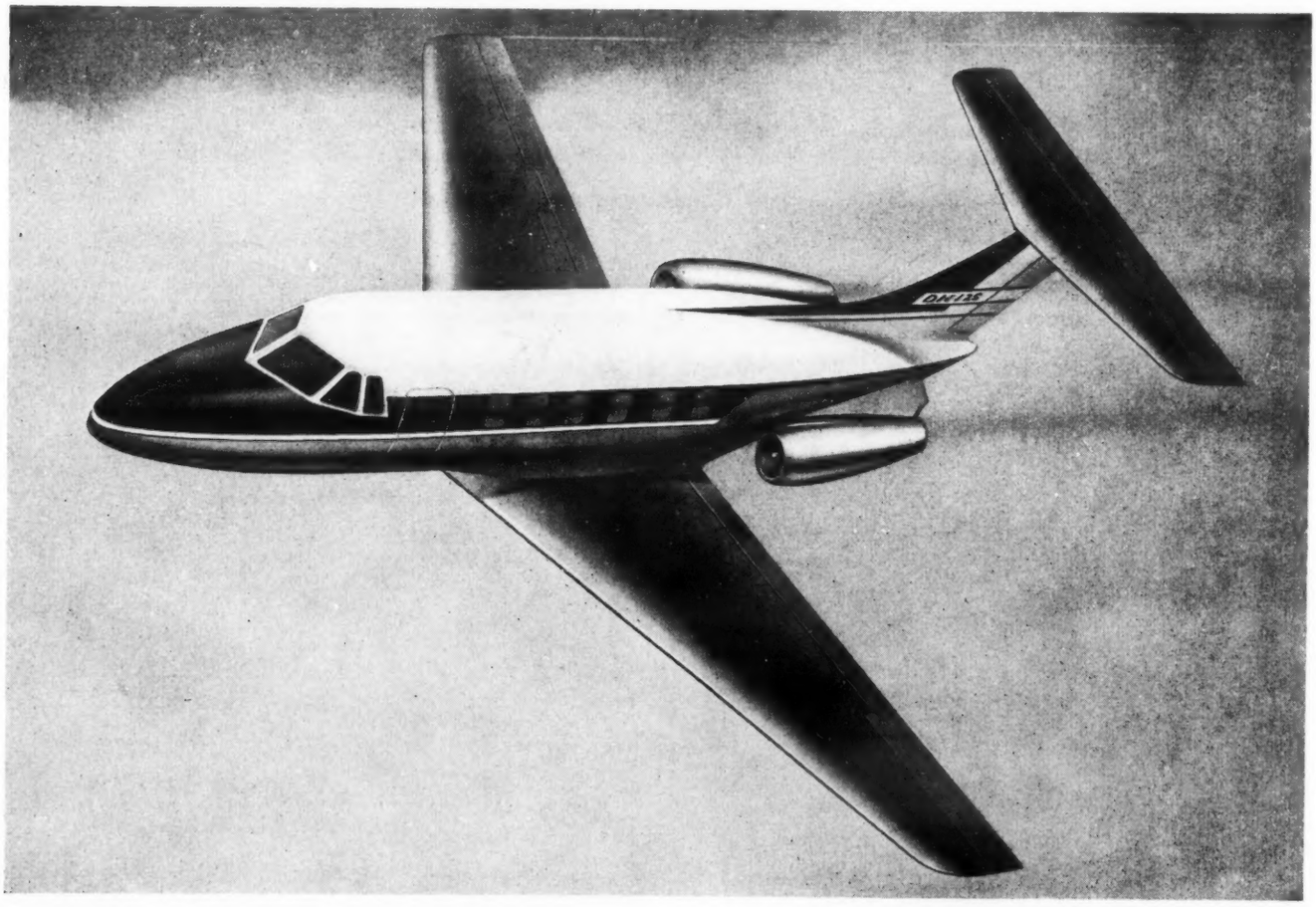

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The IATA Symposium on Supersonic Transport

by C. H. Jackson, Vice-Chairman of the Symposium*

The IATA Symposium, to which so many references have been made in the last few months, has now come and gone. Very likely many of the delegates departed feeling some relief that their further thinking, let alone action, on supersonic transport would not be required for some years. On the other hand, representatives of a few of the leading airlines, and probably most of the aircraft designers, left with more positive reactions as to the effect of the Symposium, and with material for thought in what was not said, as much as in what was actually discussed; but the delegates represented such a wide variety of technical interests and background that it would be difficult to generalize on their likely conclusions. At this stage, however, IATA was not seeking conclusions, and was more intent on providing the occasion for an exchange of views between designers, operators and all others who might be concerned or able to contribute useful ideas on the many technical aspects of proposals for supersonic transport; of course it was hoped that such exchanges would produce evidence of the present state of knowledge, outline the major problems, and indicate the likely development timing.

It was, in fact, high time that the designers met the operators in relatively open discussion, because over the last few years they have been telling them, through the technical and lay Press, and at meetings of professional engineering societies, the likely shape of things to come, when they would come, and how and what the operators could pay ! How well IATA succeeded in its intention can be judged by the attendance of about 650 experts from airlines, aircraft and engine manufacturers, fuel companies, research establishments, universities, pilots' organisations, flight safety establishments and so on. In all, about 140 different organisations and 25 countries were represented. Mr. Krzyczkowski, Technical Director of IATA, and his secretariat deserve considerable credit for their preparatory work and their organisation of conference proceedings; in particular the IATA insistence that questions and papers be prepared and issued before the meeting for prior study by the delegates. This avoided the time-consuming formal presentation of papers and greatly assisted Mr. J. Dyment, of TCA, Chairman of the Symposium, in the arduous task of reviewing well over 600 questions and supplementaries.

The leading personages who opened the proceedings had suggested that the experts should not overlook the economic implications of their talks; but there was never danger of such oversight, and it was clear throughout the proceedings that the technical experts were almost over-conscious of the economic implications for airlines of the various technical matters they discussed. At no time was there any hint that airlines would ever consider economic criteria or methods other than those by which they now judged new aircraft; when costs were discussed later in the proceedings and clearly only very superficially, some designers tentatively suggested that whilst the airlines' criteria were not to be dismissed, there was an evident need to take a broader view. This challenge, however, was not taken up except by the warning of an isolated economist that too much should not be expected of new approaches to costing or assessments of indirect costs.

Possibly the most challenging of the opening statements came semi-formally from ICAO, with the warning that both designers and operators might do well to recognize that Governments might not be willing to build, extend or strengthen runways merely for supersonic transports, and that if such aircraft were to be introduced, the operations might need to be confined by existing developments for subsonic aircraft. Clearly there could be various reservations behind such a warning, but in later debate designers were firm in their reassurances to operators that this requirement would set no problem; although these assurances were well received, there were undercurrents of doubt from operators now concerned with scheduling on the basis of available landing performance and landing runs, and who even now are looking at further aids to landing to improve their operational regularity. Against this background of experience the landing attitudes and speeds envisaged for some of the supersonic proposals seemed to require further examination. Naturally, this led to consideration of the questions raised on the prospects for that particular form of variable geometry known as variable sweep, as a means of combining normal approach attitude and speed with the best aerodynamic shape for supersonic flight. The designers' responses were an interesting mixture, ranging from outright rejection of the conception because of the problems of development and testing, through guarded comments that there were difficulties, particularly on trim, but nevertheless there might be possibilities, to even more guarded hints that it was being studied, and to outright enthusiasm from one agency for the practicability and prospects of achievement within the period that designers were considering.

Inevitably, there was much discussion around the arguments on design in light alloy for Mach 2 cruise speed, against designing in steel for Mach 3. The proponents of the former highlighted the considerable addition to development time and the costs required to perfect knowledge of the characteristics and working of the new materials needed for Mach 3, and maybe for the need for a new fuel. This was contrasted with the scanty reward in journey time that might be achieved. The designers in steel almost supported their opponents by recognising these problems, by arguing about methods of construction in steel, and even by admitting that, to start with, it might be Mach 2.7 in steel against 2.2 in light alloy; but they then made fair way to disarming them by referring to the potential for speed development of an aircraft built in steel, as against one built in light alloy. It is, however, doubtful whether the latter argument was fully accepted by all delegates because it was associated with undefined periods of time or type development and, moreover, "development of speed" potential in a given aircraft is not supported by past experience. An interesting point in this discussion, at least for those aware of the background, was the divergence of views of some of the design teams on the case for "honeycomb" construction for steel structures.

The material experts helped neither the Mach 2 enthusiasts nor the protagonists of Mach 3 in pointing out the deficiencies in the state of knowledge about the effects of prolonged periods of soaking at high temperatures, or the effects of temperature variation on material characteristics, and therefore on inspection procedures and on airframe life. On balance, it is suspected that the delegates might have been equally divided in their views on the case for a cruising speed of about Mach 2.2 as against one of Mach 2.7; fuel specifications and fuel costs were perhaps the uppermost considerations.

Rather surprisingly, the designers as well as the operators were prepared to recognise the sonic boom, and in particular the possibility of a swathe of noise below the cruise path of an aircraft in supersonic flight, as the dominating question. Both agreed that the evaluation of this noise and of subjective reaction to it could determine whether or not a supersonic transport ever would be built. It might prove no problem at all; on the other hand, it might rule out flight over populated areas. Many operators shattered the designers' ideas of an alternative and solely trans-oceanic outlet by saying that, in the latter case, there could be no economic case for the aircraft. This discussion had its lighter moments, with ardent defenders of the peace of wild life, including the "whooping crane" in particular; but one spokesman, much concerned with operations over the extensive under-developed territories of his own continent, refreshingly remarked that from his experience wild life and local populations did not mind at all, and "off-the-floor" asides from some airlines' representatives suggested that he might not be alone in this view. There was no doubt, however, that this question

* Assistant Chief Engineer (Special Duties), BOAC.

preoccupied the operators; they and the designers clearly must seek information from the NASA and other agencies and authorities if they are ever to be in a position properly to assess the case for the supersonic transport aircraft. The problem was recognised as being distinct from that of noise in airport environs, on which the designers were hopeful and reassuring.

The sonic boom problem inevitably became associated with some of the discussions on best cruising speeds on the grounds that the lowest altitude at which transition to supersonic flight would be permissible would dictate an engine installation appropriate to Mach 3 cruising speed and altitude. This suggestion, however, evidently requires further debate when more design information is available.

The operators continually probed for information on the actual shape of things to come, and sought ideas as to likely operational range and seating capacity. There was an evident desire on the part of some to ensure that the first supersonic transport could match the maximum range capabilities of the subsonic jets, and to avoid scheduling and frequency problems by achieving the present order of seating capacities. It seemed evident that, whilst designers of long-haul aircraft would not readily go below about 130 economy seats, the problems of runway strength and likely aircraft weight could prevent their going much above this figure. This discussion also revealed some contrasts between Mach 2 and Mach 3 designers in regard to fuselage widths and to the practicability of maintaining the 6-abreast seating standard. Some intending passengers might be slightly relieved to read this. They might also have been encouraged by the insistence of some airlines on designers' recognising that a shorter sector time did not warrant less than present economic standards of comfort for the long-haul passengers (those making journeys of, say, 15-20 hours from Europe to Australia, or even journeys of half that length from Europe to the West Coast of America). Whilst conceding this point, designers disappointed operators in their hopes of long-range capability, for none would promise more than the classic North American operation, say from London, Paris or other such westernmost European points to New York.

As if to reassure operators on some prospects of operational and commercial flexibility, though at the same time causing dismay to manufacturers about their sales opportunities and estimates of first costs, the French designers had ideas on medium-range, medium-capacity aircraft. They apparently either had no inhibitions about sonic booms or did not elect to debate this issue; perhaps it would be guessing too wildly to suggest that this reticence might have concealed some interest in the lowest range of supersonic cruise speeds. The discussions concerning the conception of a medium-size aircraft led to interesting reactions from one USA designer, who thought that the resulting splitting of the market might force up the first cost of a long-haul project by as much as 25%. Clearly, however, all such estimates are very preliminary, in fact they can barely be called estimates, as they did not even spell out, for example, the effects on cost and timing of the background assumptions as to Government support or as to the requirements for airworthiness testing and pre-commercial flight experience.

It would be impossible, in a short article, to summarise the ground covered by the groups discussing operational and design problems. A special note might be taken of the operational warning that, if the supersonic transport required aids and systems for ATC and navigation going beyond the as yet unsatisfied needs for subsonic aircraft, experience with such aids must be obtained before a supersonic transport could appear in service. The prospect of concurrent introduction of new systems and a radically new speed of operation was seen as almost unacceptable. The solutions of the detailed technical problems of any new systems, and even consideration of issues such as whether or not cockpit windscreens could be covered in cruise flight, seemed secondary to decisions as to what systems would really be necessary, and as to how and when they could be available. Some of these discussions were related also to the apparent absence of a sustained attack on the problem of the routine provision of meteorological data for very high altitude operations, though this question was well broached in a useful paper from McGill University. Hazards from man-made or cosmic radiation at high altitude were also reviewed in this context owing to their possible effect on aircraft routing and scheduling. The current indications, however, seemed to infer that there would be no problems from this source; nevertheless, some differences in the views expressed again pointed to the need for more information.

Another significant aspect to this discussion was the reluctance of the airlines' operational representatives to concede that the development of new aids, let alone their timing, would allow the reduction of fuel reserves below the standards now deemed appropriate to efficient long-haul operations. The reasons for this outlook are understandable, but the "snowball" effect of fuel reserves on the weight and cost of a supersonic transport are such that we have not heard the last of this argument. It might well appear again in attempts to assess the case for or against variable geometry as a means to improve the efficiency of subsonic flight, either in the flight regimes normally determining fuel reserves or, if shown to be necessary, because of the noise problem in flight over populated areas.

Naturally a great deal of routine material was considered during the design discussions and, on the whole, the operators received answers as reasonable as could be expected at this date to questions on control and on engineering systems. It was, perhaps, a little surprising that there was so little discussion of the problems of non-metallic materials in system seals, lubricants, system fluids, electric insulating materials, adhesives and so on, some of which might be primary issues in timing the development of any aircraft approaching the Mach 3 cruise speed. Possibly, however, the operators regarded these as secondary to their concern that the advance of knowledge of materials for primary structures might not match the progress of aircraft design, thus presenting the operators with new problems of inspection and lifeing of structures as well as of components.

Another problem, only briefly discussed because there was little to say at this date, was that of international agreement on the applicable airworthiness standards. The problems arising from the current procedures for reciprocal validation of certificates of airworthiness, and of overhaul processes, have in the past led to significant costs. It would seem that such difficulties must be removed if a relatively small number of supersonic transports, manufactured by only a very few firms, appear in international operations, the economic pattern of which may require a greater degree of equipment pooling than is now achieved. This problem is, perhaps, secondary to the question of how much testing and pre-service flying would be required before a supersonic transport could be certificated for commercial operations; but past experience has shown that it could be an important matter for both manufacturers and designers. However, open discussion of this problem in front of the airworthiness authorities of the countries represented has probably done good in drawing their attention to its significance for operators.

It is difficult to reduce the discussions of the Conference to a few concise conclusions. One could detail areas of doubt, recognise the magnitude of problems to be overcome, and grade them in order of importance; but this would amount to no more than a statement that, on the evidence discussed at the Symposium, the case for the supersonic transport has not yet been proved in terms either of public service or of economic advance. Even so there remains the niggling thought that designers might have refrained from presenting the more favourable trends of some of their investigations.

What is certain is that this atmosphere of doubt should not be allowed to retard the advance of design studies and research. The supersonic transport at this date may appear to be a rather ill-defined promise for the early 1970s; but as such it is beginning to have an inhibiting effect on consideration of the proper development objectives for air transport, including that of subsonic speed. An extended period of such uncertainty would be unhealthy for both manufacturers and operators, and it can only be hoped that government authorities and design and research organisations will set a reasonable limit to it by attempting to obtain the information for proper assessment within the next two years.

It has been suggested that very little improvement in the economics of subsonic aircraft is possible. If so, technological and industrial pressures might make the development of the supersonic transport inevitable. This would at the same time be a natural response, subject only to the problem of the supersonic boom, to community demand for high-speed communications. Such generalised thinking was not however reflected in the delegates' papers or discussions. If the thought was there at all it was in the form of the two questions: "when ?" and "at what cost ?". As to the first, delegates may have concluded "not before 1970 but maybe before 1975"; as to the second no answer was found, and delegates could do no more than reaffirm their present cost criteria. ◆◆

Air Traffic Control is Not Out of the Wood

How to reduce the danger of collisions in maritime and air navigation by means of land-based and ground-based aids was the theme of the "three-nation Conference" which took place in Dusseldorf from May 16th to May 18th 1961. Over 500 specialists from 15 countries attended this Conference, which was organized jointly by the British Institute of Navigation at the Royal Geographical Society (London), the Institut Français de Navigation (Paris), and the Ausschuss für Funkortung (Dusseldorf).

In the aviation sector, 37 addresses were given by representatives of official organizations, of the electronics industry, of air traffic control, and of airlines; these served to give a comprehensive picture of the problems as they are today and of the efforts made towards their solution. The discussions, although continued in the intervals and in the evenings, were all too short, but they did give those taking part some opportunity of elaborating their points of view, and it became quite clear that the opinions of the various interests were in some respects very divergent.

All were however unanimous on one point, namely that the danger of collisions is a sore point in air transport, and that no stone must be left unturned to reduce it to an absolute minimum. It is because the responsible authorities omitted, or were not in a position, to take the necessary steps for increasing safety in good, time that they are now confronted with a situation in which they themselves complain about the inadequacy of the air traffic control system.

*

To maintain the required safety distances between individual aircraft involves a waste of airspace which, with the growing air traffic, is becoming more and more intolerable. Radar can, of course, give valuable assistance at points of great strain but, given the present state of the art, it is not a universal panacea. Apart from the fact that, if radar is used on an extensive scale in air traffic control, technical inadequacy and human failings may even represent an additional source of error, detection in the third dimension, i.e. determination of flight altitudes, is still a pipe dream for civil aviation.

Precise aircraft navigation—not only in theory by providing ground and airborne equipment, but also in daily practice by the careful use of such equipment on the part of the pilot—is a *sine qua non* of close separation. Whilst it is true that VOR and DMET systems permit relatively accurate navigation on medium ranges (the advantages of the Decca were also mentioned at Dusseldorf), the accuracy and reliability of long-range navigation, particularly over the North Atlantic routes, is still in need of improvement in more than one respect. Until exact and continuous fixing is a reality, one cannot even think of reducing the norms for separation nor entertain lateral separation, which has hitherto been used in a limited way only.

Not only reliable navigation but also the rational use of airspace and the avoidance of collisions depend to a considerable extent on ground stations being able to obtain information effectively, as well as on the air/ground/air exchange of information. If radio communication with aircraft over the North Atlantic is often greatly hindered by atmospheric conditions, the R/T frequencies used for close range operations are for the most part so overloaded that pilots are unable to pass even important items of information. This is why it is considered appropriate in the first place to make uninterrupted detection of aircraft by ground a reality and in this connection radar offers certain possibilities. In any case, it is necessary also to be able to obtain impeccable altitude information and to simplify aircraft identification, to both of which ends secondary radar could materially assist. On the other hand there is no doubt that, whilst radar displays the momentary position of both controlled and uncontrolled aircraft, it is not able to give information about the pilots' immediate intentions in respect of the movements of their aircraft.

There seems therefore no alternative to the automation of the data link between aircraft and ground stations, as both the air traffic control authorities and the airlines are endeavouring to stop visual flights, at least in a considerable portion of the airspace. Positive control of all aircraft would, however, require considerable automation of ATC procedures, to relieve the controller of time-consuming routine and provide him with advanced aids. In this connection the competent authorities set great store by electronic computers. It is expected that such computers would independently process the diverse information fed in by ground stations, or transmitted by aircraft by means of a data link, and that they would provide the controller with a synthetic representation of the flight situation together with a display of potential conflicts (and their solution). The industry is, moreover, working on systems for digitalising the data obtained through radar, and also of feeding this information direct into the computer.

In order to reach the target of positive air traffic control and extensive automation, considerable efforts are still necessary in both the technical and operational fields, since systems, if automatic, must work with an extremely high degree of reliability and must not break down even in the face of unforeseen situations. It will also be essential in one way or another for airborne equipment to be brought into the system, although the owners of small executive and tourist aircraft cannot, of course, be expected to install equipment which is expensive, heavy and bulky.

The plans for the Eurocontrol project are of particular interest. This organization is in the enviable position of being able to build from scratch, without having to take existing installations into consideration. Even if it takes years of research and testing before the project is realized, the opportunity is at hand for developing the germ of today into an air traffic control system which comes as near to the ideal as is possible, given dependence on men and machines.

*

In past years, one could sometimes not avoid the impression on the one hand that the air traffic control practitioners think on too conventional lines and are very slow in responding to modern methods, and on the other that the engineers in some ways make rather light of the many imponderables which arise in practice in air traffic control. In Dusseldorf, it again became clear that the industry is doing its best to build modern and reliable ATC aids. Electronic computers, digital radar, data links, synthetic representation of the air situation etc. could undoubtedly contribute to bringing about a state of affairs one day, where air traffic would no longer limp behind other branches of aviation, as is the case at present. However there were also voices in Dusseldorf, not to be ingored, which warned against overestimating the scientific and technical possibilities.

In a complex short-range traffic region with heavy traffic density, the necessary programming of an ATC computer might turn out to be impossible. It may well be that, at the focal points of air traffic, the "computer" inside the controller's own head may, for years to come, prove to be the most effective means of preventing collisions.

Fortunately, good use was made of the opportunity offered by the Dusseldorf conference for direct exchanges of views, and for reconciling theory with practice and technical with operational viewpoints. The candid conversations between engineers and controllers which were, so to speak, conducted outside the "usual channels," should be considered one of the main successes of the Conference. It is to be hoped that all participants take to heart the advice given in the final address to the Conference, namely to treat the discussions as no more than a prelude to business.

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INTERNATIONAL MEETINGS AND CONFERENCES

June 19th-21st: ARS, Heat Transfer and Fluid Mechanics Institute Conference, Univ. of S. California. Los Angeles, Calif.

June 19th-21st: French Astronautical Society. Space Flights and Re-entry Trajectories (under the auspices of Astronautical Academy). Paris.

June 19th-24th: ICAO 13th (Extraordinary) Session of the Assembly. Montreal.

June 21st-23rd: Airlines Electronics Engineering Committee, General Meeting. Miami Beach, Fla.

June 21st-25th: Fourth Round-Germany Flight, organized by the German Aero Club. Brunswick.

June 21st-July 1st: INTERPLAS 1961—International Plastics Exhibition and Convention. London.

June 23rd: French Astronautical Society. French/Italian/English meetings on Sounding Rockets. Paris.

June 25th-30th: Symposium on Electromagnetic Theory and Antennas. Copenhagen.

June 26th-30th: IMEKO 1961 (International Conference on Meteorology and Instrument Construction). Budapest.

June 26th-28th: First European Symposium on Space Technology. London.

June 26th-28th: IRE, Fifth National Convention on Military Electronics. Washington.

June 28th-30th: Institute of Navigation, Annual Meeting. Williamsburg, Va.

June 30th-July 3rd: Thirteenth Round-Sicily Air Race, organized by Palermo Aero Club.

July 6th-8th: "La 1000 km Aerea Internazionale" ; Rome-Turin. Organized by the Aero Club of Italy.

July 6th-8th: Lockheed Aerobatic Trophy and King's Cup Air Race. Coventry.

July 7th-29th: Soviet Trade Fair. London.

July 9th-14th: ARS, Fourth International Conference on Bio-Medical Electronics and 14th Conference on Electronic Techniques in Medicine and Biology. New York.

July 14th-16th: Pyrenees Air Tour.

July 14th-23rd: Fifth Gliding Competition at Angers.

July 17th-21st: AGARD Fluid Dynamics Panel. Subject : "Use of Rocket-Propelled Models in Flight Research." The Hague.

July 24th-26th: AGARD Avionics Panel Technical Meeting. Subject : "Microminiaturization." Oslo.

July 24th-26th: AGARD Structures and Materials Panel. Specialists' Meeting of the Material Group. Oslo.

July 25th-26th: Hispano-Portuguese Rally.

July 25th-Aug. 10th: International Trade Fair and Aviation Exhibition. Chicago.

July 27th-28th: 11th AGARD General Assembly. Subject : " Scientific Goals of Space Exploration and Research." Oslo.

No Demand for U.S. Airline Shares at Present

by Scott Hershey

Despite a booming stock market in recent weeks, airline, aircraft and missile stocks generally have failed to respond to the upsurge. Nine airline issues, for example, had recent prices well under their highs of the past ten years. Ten issues listed under missiles and aircraft also had recent prices well under their highs of the last ten years.

TWA, to cite a carrier which has been much in the news, has been as high as 35 ½. A recent TWA price was 16 5/8, which compared with a high for the year of 18 ¼ and a low of 14 ¼. Wall Street is watching TWA with particular interest since its financial and top executive overhaul.

After years of coping with the unpredictable Howard Hughes, whose Hughes Tool Company has controlled TWA, the line is now under new management. Charles C. Tillinghast is the newest of a long line of presidents. Of more interest to the financial community is the election of Ernest R. Breech as Chairman, succeeding Warren Lee Pierson, who retired after 14 years as Chairman and who is widely and favorably known in the airline industry around the world. Mr. Pierson will, however, continue as chairman of the executive committee.

Mr. Breech is not unknown to the aviation industry, although most recently, until his resignation, he was Chairman of the Ford Motor Co. He was a director of Transcontinental and Western Air, Inc., TWA's predecessor. He was formerly chairman of North American Aviation, before his affiliation with Ford.

In December 1960 he acted as one of the three trustees of the TWA backers, to whom Hughes Tool transferred the 78 percent of the TWA capital which it owned. This agreement was concluded by TWA in order to guarantee a loan of originally $265 million to cover the acquisition of 27 Boeing 707s. At the end of April 1961, Boeing and TWA signed a further $187 million lease-purchase agreement covering 30 turbofan passenger transports. By August this year, TWA should also receive 20 Convair 880s, and by 1962 its total jet fleet should amount to 77, involving some $500 million.

With a man of Breech's stature, and a new president, TWA stockholders, as well as the Wall Streeters involved in the new financing, believe that TWA may well be on its way to a more sound financial footing. The long-range prospects for the airline are considered good, despite a heavy loss in the first quarter of this year, during which the net loss amounted to $9,326,000 after tax credits, as compared with $6,826,000 in the same period a year ago.

To investors who have liked Pan American and stayed with it during its ups and downs, the big volume market of past weeks has meant little. For example, Pan American has been as high as 35 ¼ in the past ten years. A recent price was 18 3/8, a 47 percent drop.

The drop in Capital Airlines amounting to 73 percent has of course topped all others, with a high in the past ten years of 42 ½ and a recent price of 11. Since the merger of Capital with United Air Lines has finally been approved and will soon become an accomplished fact, here is another situation which Wall Street is watching with interest.

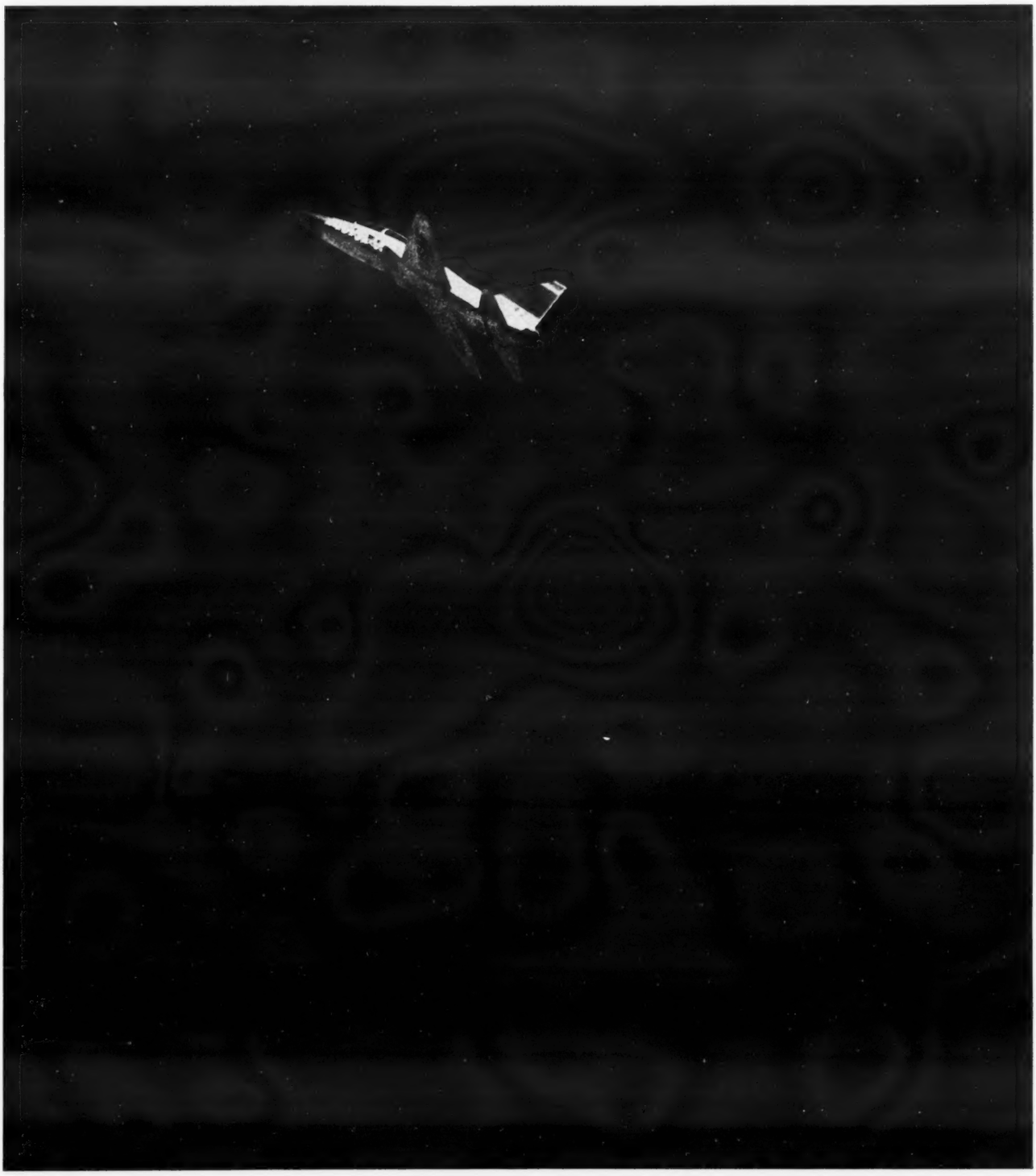
United had a recent price of 47 1/8. Its high for the year was 48 and its low 34 5/8. Non-recurring expenses arising from the merger are expected to be more than offset by a determined cost control program according to W. A. Patterson, United's president. United's net loss, after inclusion of a $535,000 gain on aircraft sales during the first quarter was $209,000 or five cents a share, as against a loss in the comparable 1960 period of $2,767,000 or 70 cents a share, including a gain of $1,379,000 on aircraft sales. "The merger offers opportunities for growth and enhanced profit," said Mr. Patterson in a first quarter statement to shareholders. "Operations on Capital's southern routes will improve our seasonal traffic balance, while consolidation of operations at 12 major cities will have further economic benefits."

At about the same time as Mr. Patterson issued his statement, C. R. Smith, President, American Airlines, which cleared a profit last year but has this year been operating at a deficit, said there was more financial turbulence ahead for the nation's airlines. Mr. Smith said that the airline history of 1946-1949, when earnings stayed at one percent of investment level for four years, may well repeat itself. He declared that if the Civil Aeronautics Board continues its present "lavishness" in expanding the air route systems, "either the airlines will return to Government subsidy or else they will go bankrupt." Net loss of American in the first quarter was $1,966,158 against a net loss of $453,288 in the 1960 period. The loss was after the inclusion of $385,059 for profit from the sale of property this year against $463,680 from that source a year ago. A recent American stock price was 21 3/8, against a high of 24 ¾ and a low of 21 for the year.

Bolstering Mr. Smith's dire warnings was the fact that last year the 12 major domestic airlines made their poorest profit-showing in a decade. Combined net profits after taxes and interest were slightly more than $1,000,000 despite record revenues. The rate of return on investment was 2.9 percent, far below the 10.5 per cent which the C.A.B. has said is required for adequate airline earnings.

On the somewhat brighter side, KLM Royal Dutch Airlines reported net earnings after all charges and adjustments amounted to $2,718,000 or $1.87 a share for last year. This, however, was a drop from $3,875,000 or $2.68 a share the year before. KLM has remained fairly steady, with a high of 27 3/8 and a low of 25 7/8 this year.

T-38: Fastest Step to combat readiness



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Rate of Climb (Sea Level)	**30,000 ft. per minute (at take-off gross weight 11,550 lbs.)**
Propulsion	**Two J85-GE-5 afterburning turbojet engines. Thrust (each engine) — 3850 lbs.**
Take-off Distance	**2400 feet**

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He hurried to the airline's office, and only when he had obtained confirmation of this story was his confidence in his wife restored. At the same time he lost confidence in his Government.

A Publication by KLM Royal Dutch Airlines

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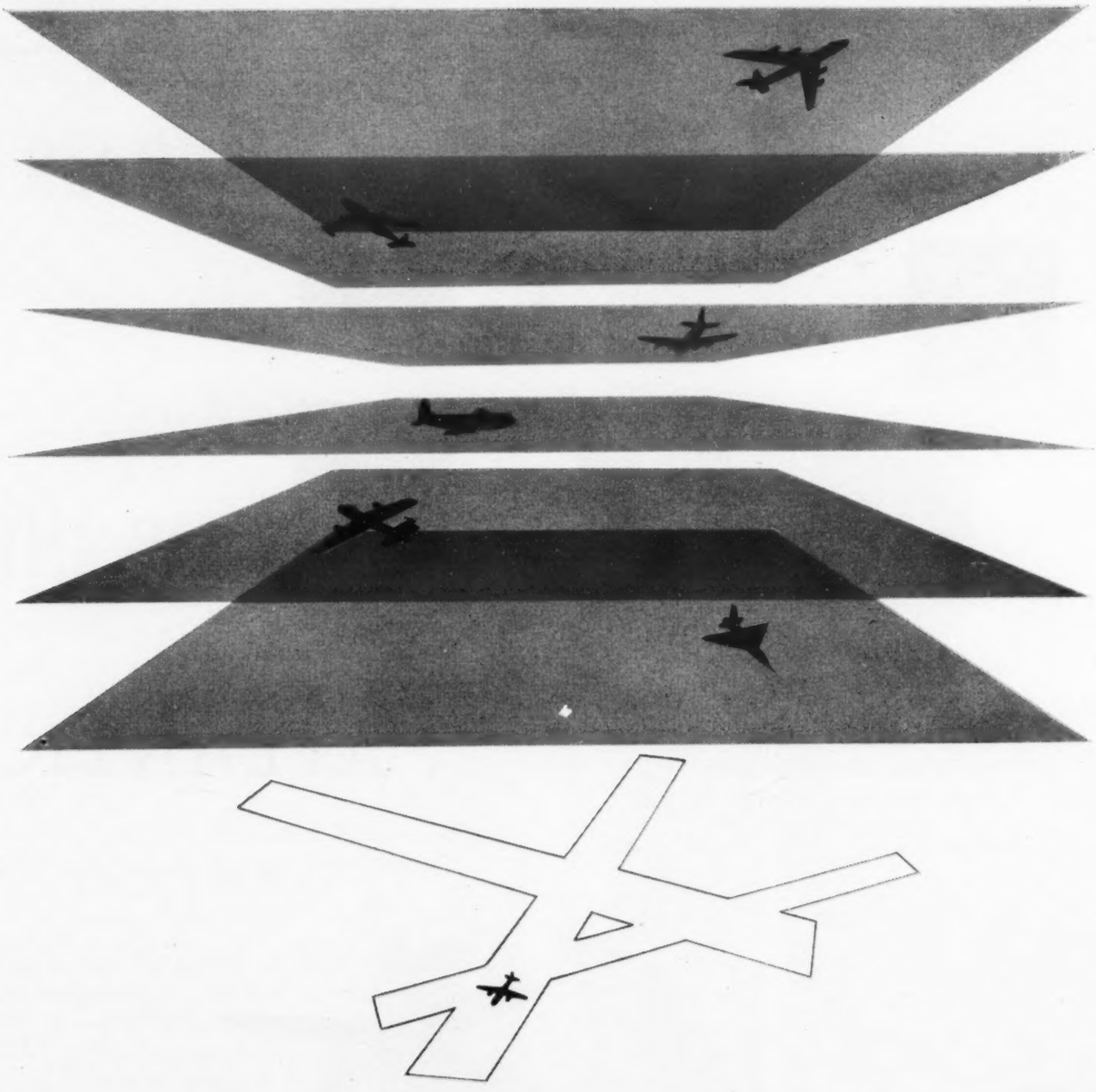
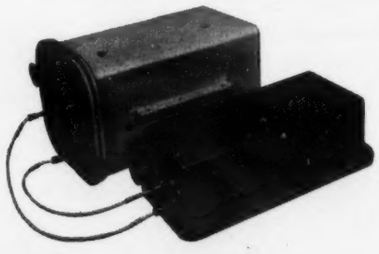


Cubic MOPTAR—key to jet age collision avoidance



MOPTAR requires only this miniature transponder in each participating aircraft.

Using only stationary antennas, with no moving parts, a single Cubic MOPTAR ground station (like the ones already in operation) can be expanded to provide 3-dimensional position data on as many as 400 aircraft. The expanded system can provide terminal and enroute surveillance, positive aircraft identification, conflict prediction, and navigation data. To avoid collisions, MOPTAR space-time information would be automatically and continuously processed, and potential-conflict data transmitted to the aircraft involved. MOPTAR, combining Cubic precision DME (Distance Measuring Equipment) and AME (Angle Measuring Equipment), was developed for the United States Air Force and the Federal Aviation Agency. For more information, write Dept. I-102, Cubic Corporation, San Diego 11, California.

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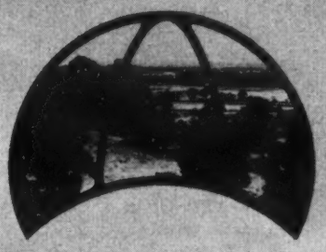
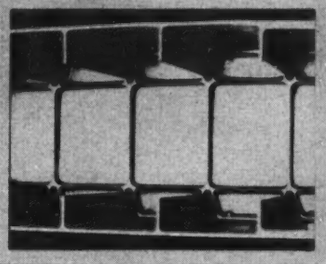


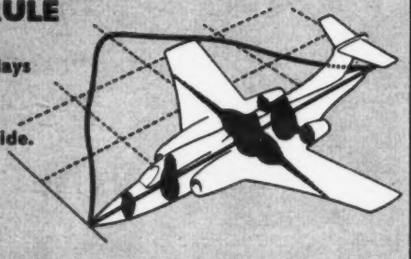
STRUCTURAL LONG LIFE

The BUCCANEER was designed to withstand prolonged low-level turbulence at high speed.



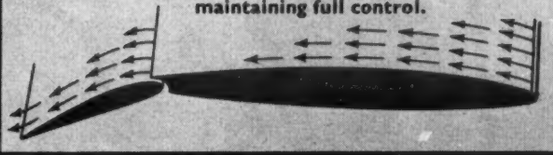
AREA RULE

Area rule delays the drag rise and provides a smoother ride.



BOUNDARY LAYER CONTROL

Boundary layer control reduces landing and take-off speeds whilst maintaining full control.



THE BLACKBURN BUCCANEER

strikes at "**zero**" feet beneath an enemy's radar defences

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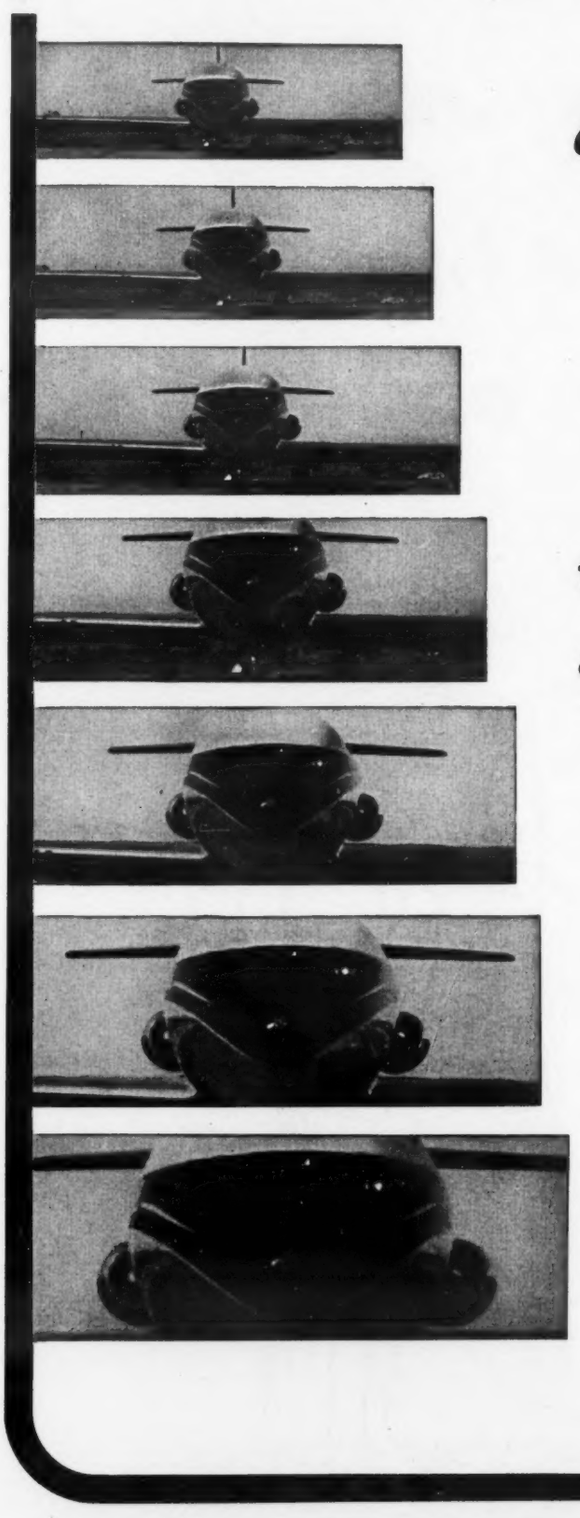

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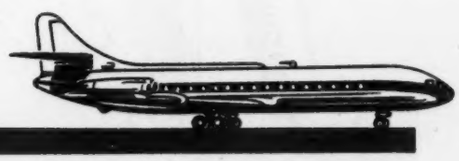

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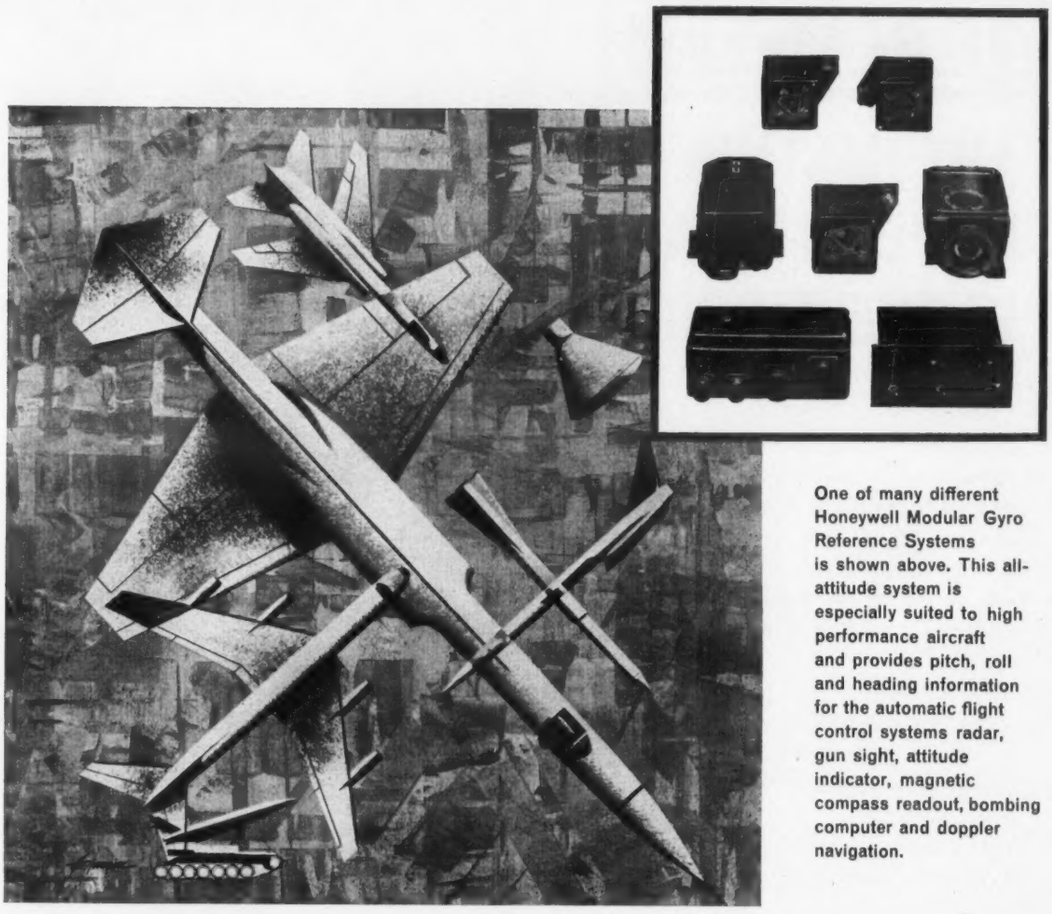

One of many different Honeywell Modular Gyro Reference Systems is shown above. This all-attitude system is especially suited to high performance aircraft and provides pitch, roll and heading information for the automatic flight control systems radar, gun sight, attitude indicator, magnetic compass readout, bombing computer and doppler navigation.

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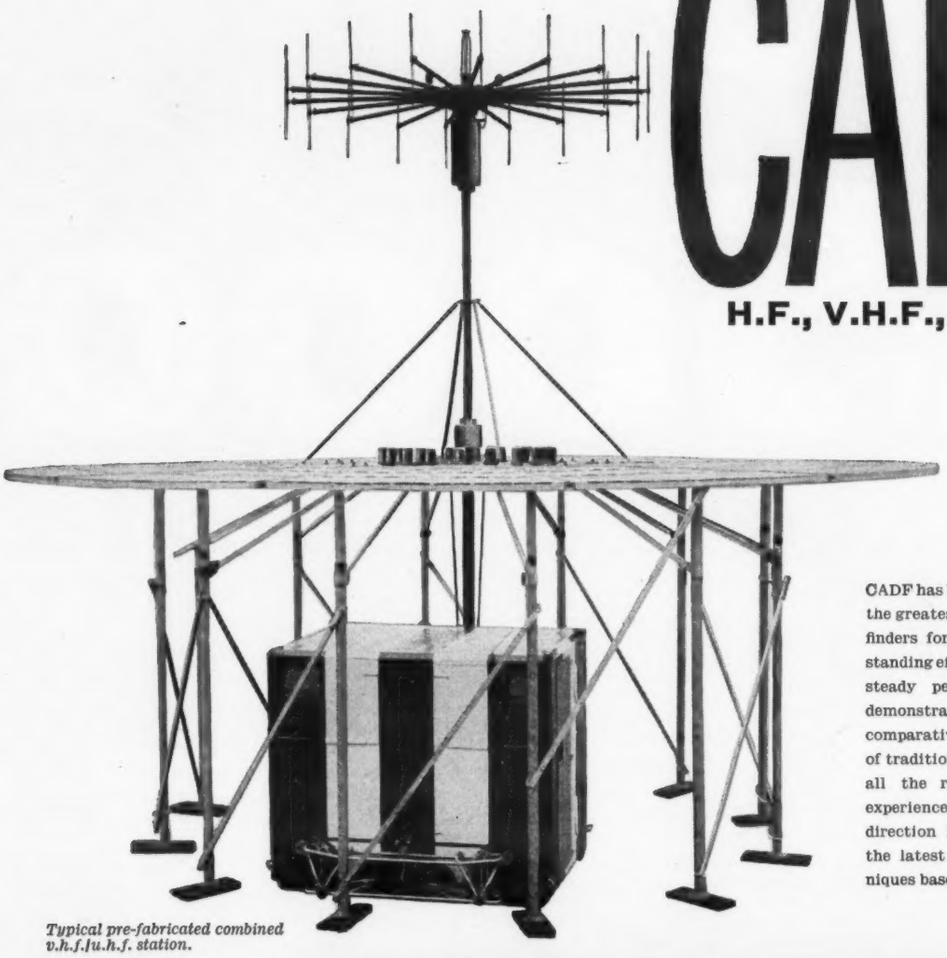

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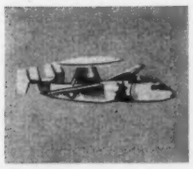

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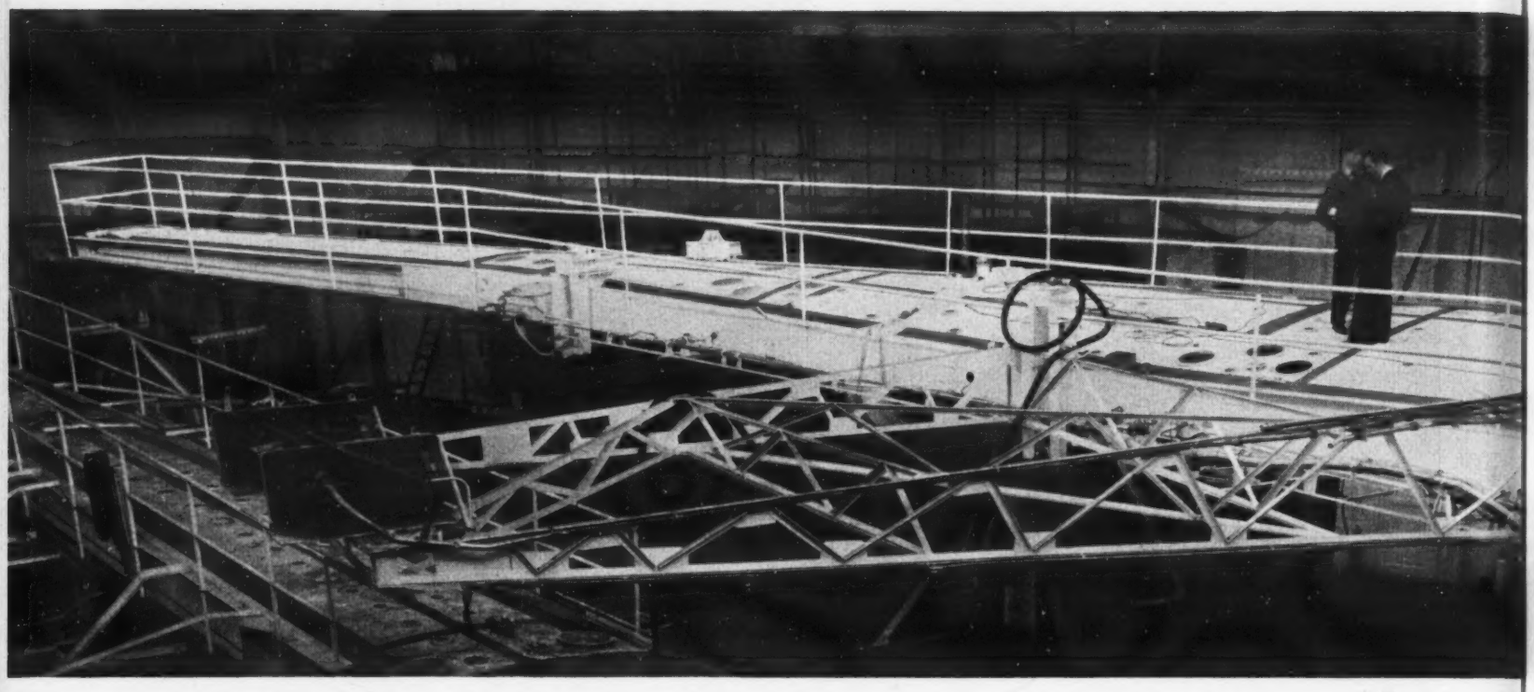
Smiths are in the picture



SM91

The Smiths Waymouth Type 4 transistorised fuel contents gauging system is fitted for testing purposes to this full scale replica of a Vickers VC.10 port wing and centre section built at Weybridge. The Waymouth system has been specified for all production VC.10's to date. It incorporates a unique fuel load control panel located in the underside of the port wing, from which ground crew will be able to control accurately the entire fuelling operation, with overloading automatically prevented. The highest fuelling rate ever achieved—1,000 Imperial gallons a minute—enables the VC.10's thirst to be slaked in some seventeen minutes.

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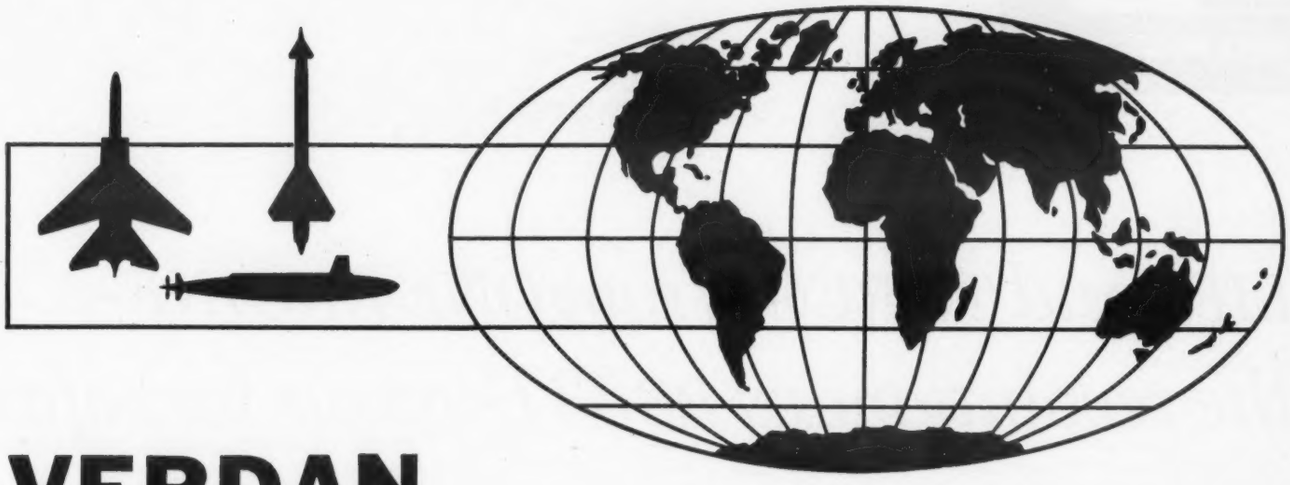

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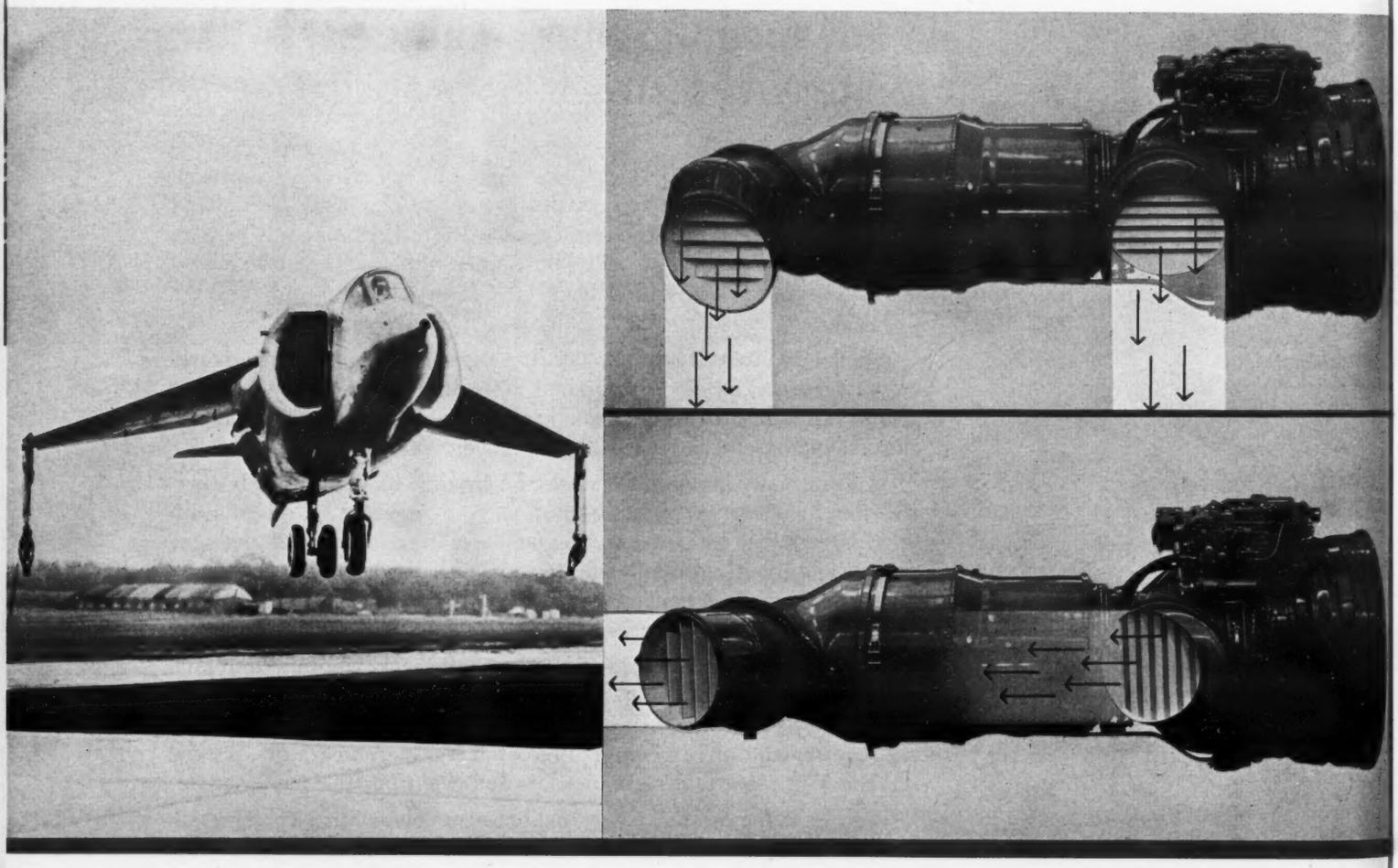

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VTOL, STOL and normal take-off capability in the same aircraft. Suitable for subsonic or supersonic applications.

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Techniques Galore

In the space of a few weeks, the world of aviation, and indeed the whole of humanity, has witnessed the exploit of the Soviet astronaut Gagarin, as well as the ballistic flight by Shepard which successfully concluded the first phase of the American *Mercury* programme. At the same time, the air traffic equipment planners met in Montreal to discuss the possibilities of future supersonic traffic. Meanwhile, in Washington, President Kennedy was calling for the production of American space weapons to be speeded up whilst, on the other hand, relegating the B-70 programme to the status of a technical study project, since manned bombers appear to be taking second place to ballistic missiles in operational significance. This memorable Spring has also seen the X-15 in flight at a speed of nearly Mach 5 and Bristol's announcement of the first taxiing tests of the T.188, an experimental aircraft for the study of manned flight at speeds over Mach 2.

The pace of scientific and technical competition is getting hotter all the time. A tremendous investment in effort and money is making it possible to race ahead to enlarge the field of research, and to put forward a dozen new projects to take the place of any idea which becomes obsolete. The object which the Editors have set themselves in this number of *Interavia* is to present the main facts as a guide through this maze of development.

It is astonishing that, although the *Mercury* project came into existence barely four years ago, i. e. shortly after the Russian dog *Laika* orbited round the earth, Shepard's ballistic flight is already a reality. As regards the B-70, the preliminary studies for this aircraft in its present configuration started in 1955. If the Pentagon succeeded in finding the money for the whole of the B-70 construction programme as originally conceived and if, one day, a hundred of these bombers were to replace the B-58's in S.A.C., they would probably remain in operation until at least 1980, seeing that they could hardly be delivered to the long-range bomber squadrons until late 1966, and would then probably stay in service for over a decade. In other words, the cycle of planning, building and operating such aircraft is relatively long. And during this space of time, new weapons would make their appearance in the arsenals of the two great powers and, as a result, the interest in long term projects would diminish.

Our age is characterized by the new and, for the most part, long-term solutions which never cease to present themselves. Since it is obviously impossible to entertain them all, selection is of decisive importance. For this reason major projects entailing heavy expenditure of money and time are often never brought to fruition. When President Kennedy for practical purposes put his pen through the B-70 programme, he also appreciably slowed down the NEPA project. On the other hand, it is true that it took the Navy only four years to realise the *Polaris* weapons system, and even less for the USAF to prove the soundness of the concept embodied in the *Minuteman*.

The President of the USA is thus relying on ballistic missiles as the deterrent on which American security primarily rests. And, whatever the Air Force may say, it is clear that Washington's strategy is directed more and more against the cities, rather than the armed forces, of a potential aggressor. This is an inevitable consequence of the fact that technical progress enables both camps to protect their deterrent weapons more and more efficiently from enemy attack, leaving the centres of population and industry as the only objectives. Against targets of this type, the ballistic missile is a perfectly adequate weapon.

In his message to Congress concerning the military budget, President Kennedy conceded that there could be certain advantages in having manned long-range bombers, whose operation could be easily monitored. He added that, in order to retain the possibility of realising a weapons system of that kind, he recommended the continuation of the B-70 programme, but with reduced credits, in order at any rate to investigate the problems of flight at three times the speed of sound.

There is also a new interest in combat aircraft operating at low level. If tomorrow it were possible to penetrate below the enemy radar umbrella in low flight at over Mach 1, the enemy air defences would be faced with problems still more difficult than that of defence against long-range ballistic missiles. With the aid of computers it is not difficult to prove that, in the case of penetration at altitude, an increase in speed from Mach 2 to Mach 3 increases the difficulty of defence by only 10—15 percent, whereas fast attacks at altitudes of under 1,000 feet render defence five or ten times more difficult. Furthermore, in so far as it is a question of an aircraft of this kind as a launching platform for missiles, one should not seek complications where there are none, since speeds of Mach 3 appear superfluous for this purpose.

However that may be, the military experience gained in the construction of the B-70 is needed more urgently than ever in the civil sector. At Montreal, three tendencies emerged from the exchange of views about supersonic civil aircraft. Some have in mind a medium-haul civil aircraft for speeds of Mach 2 whilst others, for example the British, are thinking in terms of long-haul aircraft of the same speed class. A third school of thought, strongly represented in the USA, favours a Mach 3 aircraft for long hauls, especially on transoceanic routes, where the detrimental ground effects of supersonic flight do not need to be taken into consideration. But how many problems still remain to be solved in this connection!

There are noise, heat resistant materials, engines, fuels, the biological effects of high speeds and altitudes, and air traffic control, to mention only a few. In any event the B-70s, which are to be financed by the Department of Defense, could play a decisive part in solving questions of this kind, and the Bristol T.188 should give British aircraft constructors important leads in building aeroplanes for speeds in excess of Mach 2, particularly in the field of metallurgy. Intensive research is still required to produce materials which can withstand temperatures of 250 °C to 300 °C during some 30,000 hours flying time, for there is no experience whatever on which to draw. Doubtless, the necessary experience can be accumulated with such aircraft as the T.188 or the B-70.

It is to be assumed that one day commercial flying will be supersonic, and the preliminary work in that direction is already in progress. Aviation engineering does not lag behind space engineering in its efforts. The *Vostok* and *Mercury* are preparations for space travel and the military Mach 3 experimental aircraft promises to make London/NewYork a hop of under two hours for civil aviation too. Certainly there are already voices warning civil aviation against too rapid conversion to Mach 3 since it is in first place flight at the outer edge of the atmosphere, in other words semi-ballistic *hypersonic* flight, as opposed to *supersonic* flight at an altitude of 12 miles, which seems a real commercial proposition. Space gliders, such as the Mach 10 bomber conceived by Professor Sänger in World War II or Boeing's *Dyna Soar* project (cf. *Interavia* 3/1961, page 321), could thus show the way to a new category of space vehicles, which are possibly more promising than the supersonic Mach 2 to Mach 3 aircraft contemplated today. ←→

Man's First Journeys into Space

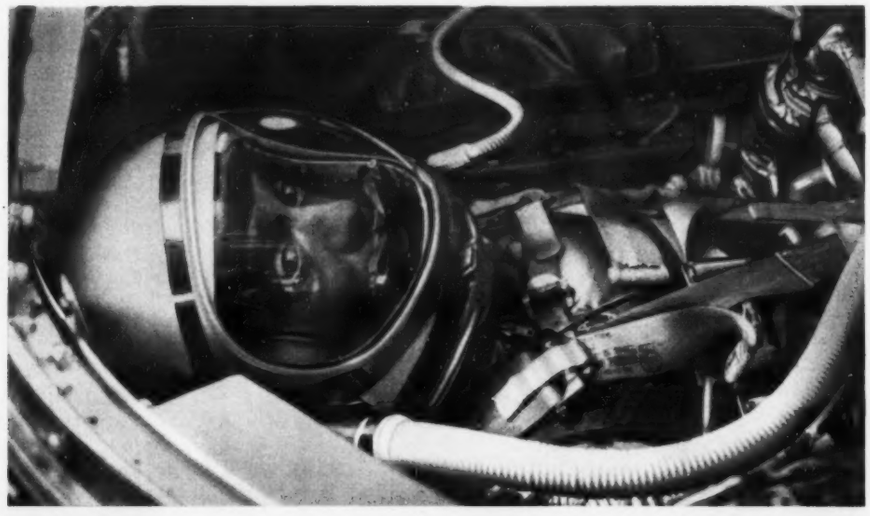
Three weeks after Soviet Air Force Major Yuri Alexeievich Gagarin landed safely "somewhere in the USSR" on April 12th after an orbital flight around the earth, the Americans recovered their first astronaut, Commander Alan Bartlett Shepard, also safe and sound, from his *Mercury* capsule, as it floated in the Atlantic after a fifteen-minute flight on May 5th.

While Gagarin's flight was kept secret until he landed, the American experiment—from the launching preparations to the recovery of astronaut and capsule—was made public down to the last detail. Even after the jubilation had died down, the Russians remained true to their principles and published only a general description of the flight, based mainly on the impressions of the "cosmonaut," maintaining an impenetrable silence regarding the rest of the experiment. At the time these lines went to print, only a few sparse details of the construction and equipment of the *Vostok* had been published, and information on the booster used was completely lacking. The following article must therefore be restricted to the American space flight programme.*

The history of the *Mercury* programme dates back to 1957, when—even before the first *Sputnik* launching—a number of American research agencies began work on manned space flight projects. At first, these met with a somewhat cool reception from the authorities, and it was not until the series of Soviet successes that the Pentagon decided to force on with these studies. Extensive calculations and thousands of tests, many of them carried out in the wind tunnels of the National Advisory Committee for Aeronautics, finally led to an overall plan for the development of a pressurized cabin which would circle the earth a number of times with an astronaut on board and re-enter the atmosphere on a ballistic trajectory. The boosters considered were the *Atlas* for earth orbits, and the *Redstone* and *Corporal* for experimental flights of a few hundred miles (the *Corporal* was subsequently rejected). Despite the "top priority" given by the Government to the project, which had in the meantime been named *Mercury*, it was not until 1958 that the main design specifications were laid down and the National Aeronautics and Space Administration, the successor to NACA, asked for tenders. Of the more than 20 companies which submitted detailed designs in December, 1958, McDonnell Aircraft was the winner. On February 6th, 1959 the company received a firm contract to develop and build twelve space capsules. Later, a follow-on contract for a further twelve was awarded. Before 1958 was out, a committee consisting of medical specialists from all three armed forces and NASA scientists had worked out a set of standards for the selection of future astronauts. A short list of 110 applicants, all experienced pilots, was made, and after a further, still more rigorous selection, seven men began training in April, 1959. At the time, McDonnell delivered the first capsule to the NASA Wallops Island test centre.

In autumn, 1959, flight tests began with *Little Joe* boosters and dummy payloads. These served primarily to test the ejection device and to study re-entry problems. In May, 1960, the first actual capsule was fired to a height of 2,500 ft without the booster, but with the aid of its ejection rockets, and recovered. On July 29th, 1960, a *Mercury* capsule was to have been put by *Atlas* into a steep re-entry trajectory and subjected to accelerations of up to 16 g. However, the booster exploded after 65 seconds, setting the programme back by months. On December 19th, success was at last achieved with a *Redstone*. The fully equipped capsule reached a height of over 60 miles and was recovered from the ocean 31 minutes after launching. A complete success was likewise scored on February 21st, 1961 with an improved *Atlas*. The capsule travelled for some 1450 miles and was subjected to accelerations of 16.5 g on re-entry.

On March 31st, 1961 the first climax was reached, when a *Redstone* carried the chimpanzee "Ham" into space. Owing to faulty operation of the thrust control system, the capsule reached a height of 155 miles, instead of 115 miles, as planned, and impacted at a speed faster than that intended. Almost four hours after the launching, the capsule was recovered slightly damaged, though the chimpanzee was none the worse for his experience. A further *Atlas* firing on April 25th was a failure, though the ejection device worked according to plan. The first manned flight was planned for May 2nd, but had to be postponed until May 5th owing to bad weather. The daily press has already published detailed reports of Alan Shepard's flight. Booster, life support



The first *Mercury* space capsule delivered by McDonnell Aircraft to NASA. The tower with the rocket motors which can, if necessary, separate the capsule from its booster during the launching phase, is clearly distinguishable. ▶

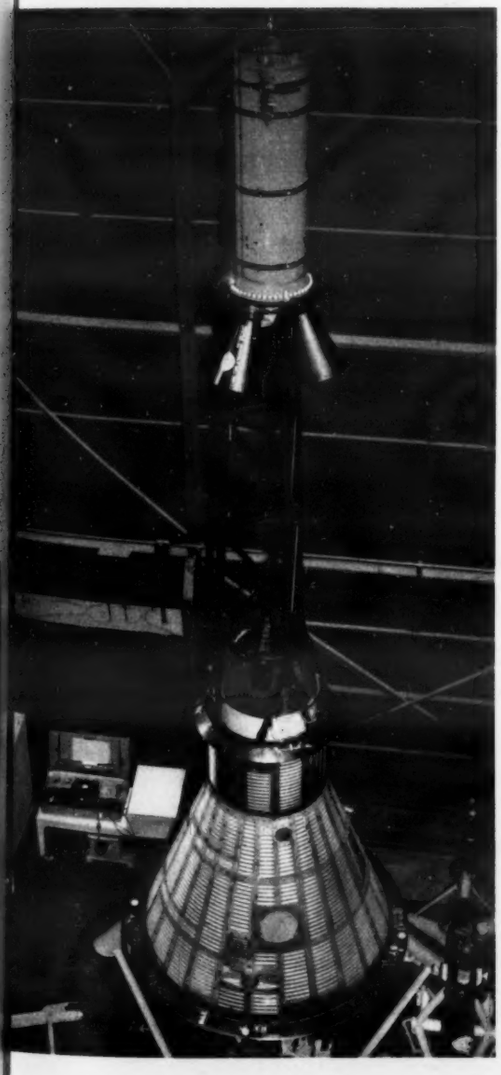
Originally scheduled for May 2nd, the first flight of a manned *Mercury* capsule was postponed until May 5th owing to unfavourable weather conditions. Owing to a temporary deterioration in the weather and a technical hitch, the launching was postponed for another two hours, which the astronaut spent strapped in his capsule fully equipped (*above*). At 1434 hours GMT the *Redstone* booster was finally launched from Cape Canaveral, and 15 minutes later the capsule, christened "Freedom 7," came down in the Atlantic 302 miles from the launching site. It was sighted by Navy recovery units, still suspended from its parachute. Four minutes after impact, Shepard was climbing aboard a helicopter (*right*), which set him down safe and sound on the aircraft carrier *Lake Champlain*.

* Cf. *Interavia* No. 5/1961, page 540.

system, recording and radio equipment, retro-rockets and landing equipment functioned satisfactorily. The capsule reached a height of 115 miles and covered a distance of 302 miles. The pilot was subjected to an acceleration of 11 g on re-entry. Reports published by the time these lines went to print indicate that Alan Shepard is in the best of health.

Structure of the capsule

Although NASA had specified the general configuration of capsule and equipment on the basis of calculations and model tests, the more difficult part of the task began when McDonnell engineers and some 2,000 sub-contractors got to work on design details. During the launching phase, the air forces and accelerations acting on the capsule are considerable, as well as vibrations in the booster; all this requires a high degree of resistance to fatigue. In addition, the capsule most protect the pilot if the booster should explode in its vicinity after the escape device has been actuated and the capsule ejected. While in orbit, the capsule will be under overpressure and must not spring any dangerous leaks even if bombarded by meteorites. There are also the effects of vacuum on the behaviour and qualities of materials, though the effects of radiation at the envisaged orbital altitudes of 100 to 150 miles are hardly to be feared. On re-entry at accelerations of over 10 g, powerful thermal stresses are encountered.



The Soviet Space Programme

While the Americans are forging ahead with a space research programme whose many-sidedness leaves nothing to be desired, the Soviet Union has from the beginning concentrated all its efforts on a few objectives: earth satellites for geophysical measurements, lunar probes, manned earth satellites. Even at a fleeting glance, the homogeneity of the calendar of Russian launchings is striking: apart from three lunar probes and a Venus probe, each launching has been the logical consequence of the foregoing one. Four weeks after they had sent the first artificial earth satellite into space, the Russians put a living creature—the dog "Laika"—into orbit in a capsule weighing over 1,100 lb. This left no doubt that the USSR was striving in good earnest to achieve manned space flight. Although it has never been officially admitted, there is every reason to believe that *Sputnik 2* was designed as a re-entry vehicle. At all events, the experiment proved that a relatively highly developed form of life is perfectly capable of surviving under the environmental conditions of a flight in space.

A second striking feature of the Soviet space programme is the continual increase in payloads. Apart from the first two satellites, *Sputnik 1* and *Sputnik 2*, all the space vehicles have weighed well over 2,000 lb (the weight of the "booster satellite" must, of course, be added to the 1,416.7 lb of the Venus probe). And the weights of the satellites designated by the Soviets as "Space Vehicle" or "Cosmic Ship" are in the neighbourhood of 10,000 lb—a fact which has to a great extent contributed to the reliability of the satellite systems. For, unlike the Americans, who have been obliged to rigorously miniaturize all their systems, the Russians have been able not only to make their equipment, in particular the life support system, more robust and by this very fact more reliable, but also to duplicate many systems. This is undoubtedly one of the reasons why they have by-passed short manned ballistic flights—at least there is no evidence of such having been made—passing straight to full orbital flight. Life support supplies aboard the *Vostok* were reportedly sufficient for a ten days' stay in space.

As for the biomedical aspect, the Soviet scientists have presumably followed more or less the same lines as their American counterparts: high-altitude rockets carrying animals; training of astronauts (also pilots, as in the USA) in heat and vacuum chambers, and in soundproof space simulators; acceleration tests on centrifuges; familiarization with the condition of weightlessness in experimental flights (in aircraft) with ballistic trajectories etc. In addition, valuable experience was gained with the "live payloads" of five satellites.

Although the Russians are, as usual, maintaining silence as regards their plans for the future, the little information they have released leaves no doubt that they intend to continue their space research programme at full pressure. In view of the high payload capacity of Soviet boosters, earth satellites for crews of several men would not come as a surprise. And although no lunar probes have been launched since the three *Luniks* in 1959, the moon can by no means have lost its interest. Finally, there are indications that the Russians are working on meteorological and communications satellites in the east of the country. ←

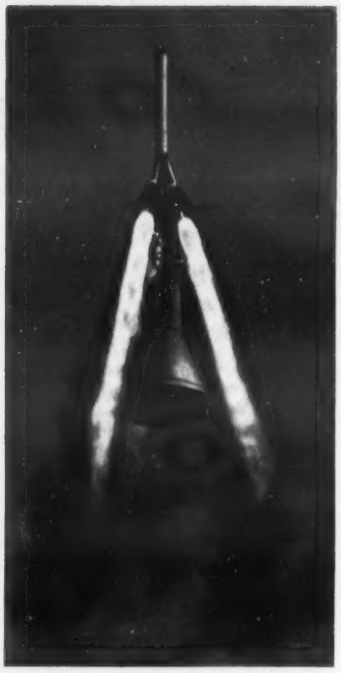
Soviet Space Calendar

Launch date	Designation	Weight	Remarks
4. 10. 57	Sputnik 1	183.9 lb	First artificial earth satellite
3. 11. 57	Sputnik 2	1,118.2 lb	Dog "Laika" on board
15. 5. 58	Sputnik 3	2,319 lb	Burnt up on 6. 4. 60
2. 1. 59	Lunik 1	2,341 lb	First lunar probe, now in orbit around the sun
12. 9. 59	Lunik 2	3,324 lb	Impacted on the moon on 14. 9. 59
4. 10. 59	Lunik 3	3,417 lb	Photographed the reverse side of the moon, now in orbit around the earth
15. 5. 60	Space Vehicle 1	9,988 lb	Life support system and dummy on board
19. 8. 60	Space Vehicle 2	10,120 lb	Dogs "Bielka" and "Strelka" on board, animals recovered
1. 12. 60	Space Vehicle 3	10,039 lb	Dogs "Pshelka" and "Mushka" on board, recovery failed
4. 2. 61	Sputnik 4	14,283 lb	
12. 2. 61	Venus probe	1,416.7 lb[2])	Launched from an earth satellite, on the way to Venus
9. 3. 61	Space Vehicle 4	10,340 lb[1])	Dog "Chernushka" on board, recovered
25. 3. 61	Space Vehicle 5	10,329 lb[1])	Dog "Zvezdochka" on board, recovered
12. 4. 61	Vostok	10,395 lb[1])	First manned space vehicle with Major Yuri Gagarin on board, landed safely after a single orbit around the earth.

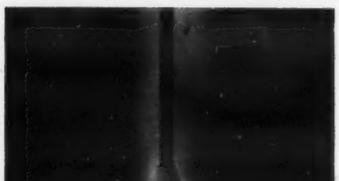
[1]) without final stage of booster

[2]) Venus probe without launch satellite

▲
In the free flight tunnel of NASA's Langley Research Center, models are tested to see whether the auxiliary parachute stabilizes the capsule before the main parachute opens.



Testing the ejection device with a mock-up of the *Mercury* capsule. During the test, the rocket motors boosted the capsule to an altitude of 2,250 ft; here the escape tower was ejected and a parachute opened to lower the capsule gently to the earth. *(Topcentre)*.



The surfaces of capsule mock-ups were heated to temperatures of over 5,500 °C by hot gas blasts, quartz lamps and furnaces. Picture shows a small fibreglass mock-up in a 2,700 °C jet of air during simulated re-entry. ▶

NASA scientists used a mock-up to investigate submersion characteristics and stability of the capsule as it floated on the water. Impact speed is normally 30 ft/sec; after rolling slightly a few times, the capsule remains vertical on a calm sea.
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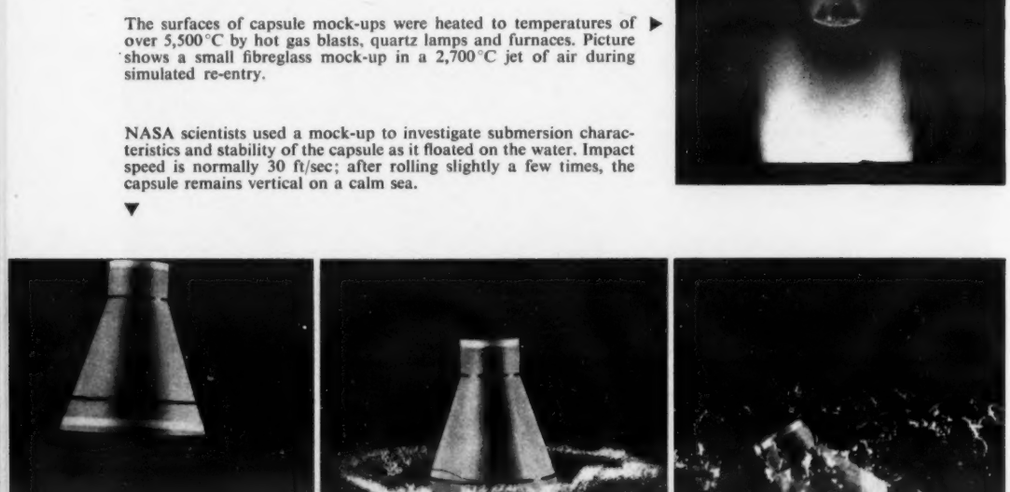


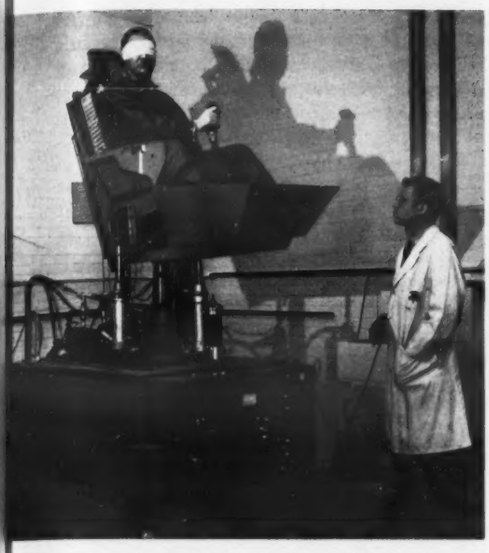
Scott Carpenter, one of the seven *Mercury* pilots, familiarizing himself with the controls of the radio system. In order to be able to practise on the controls under conditions approaching those actually encountered without wearing the full pressure suit, he uses the simulator shown here: the radio equipment is in a vacuum chamber, while the sleeve and glove simulating those of the pressure suit are at normal atmospheric pressure. The radio for the *Mercury* capsule was developed by Collins Radio Company.

In addition to heat-resistant characteristics of the outer skin and the parts of the structure immediately beneath it, this requires a construction making sufficient allowance for elastic deformations in the airframe. Here, too, there must be no leaks in the cabin.

As, like many other parts of the equipment, the astronaut cannot be miniaturized, the designers had to economize on every ounce of weight that went into the airframe. Here again, saving in weight must not be achieved at the cost of the occupant's safety.

Externally, the *Mercury* capsule looks like a television tube. On a truncated cone 6 ft wide at its base is mounted a cylindrical section which houses antennas and parachutes. As it is difficult to keep a pressurized cabin sealed under high thermal stresses and the distortions which they cause, and as the astronaut must be shielded from high temperatures, a double-wall container was found to be the best solution. Here the outer skin takes up the air forces, friction heating, acoustic stresses and meteorite impacts, while the inner wall serves to prevent a pressure drop inside the cabin. The outer skin, of integrally stiffened shingles of cobalt-base alloy, is bolted with hat sections whose flanges are welded to the inner skin. To solve the difficult problem of keeping the cabin pressure-tight, a double layer of welded metal sheets was chosen for the inner wall. To withstand the temperature gradients, a wide variety of materials are used: beryllium and cobalt alloy for the outer skin, nickel alloy for the inner skin, titanium sheets for the hat sections, and finally aluminium alloys for the pressure vessel, which is well protected from high temperatures.

Apart from the surface of the truncated cone, which is exposed to the highest temperatures on re-entry (up to 3,000 °F), the outer skin of the capsule will be heated to over 2,000 °F. Between outer skin and pressure vessel is fitted a thin layer of Thermoflex, a material composed of ceramic fibres and produced by Johns-Manville; this provides excellent insulation not only against heat, but also against noise. The same firm also supplies Min-K, a material with a lower thermal conductivity than air, which is used in *Mercury* to



With eyes closed, prospective *Mercury* pilot Virgil Grissom must remain horizontal on the simulator couch, which can be swivelled about two axes. In certain tests his task is made more difficult by artificially induced oscillations.

Among the conditions to which astronauts will be exposed is the effect of high temperatures over long periods. Picture shows Scott Carpenter on the heat test stand at Wright Air Development Center... at 54 °C.

On this test stand, designed by the Firewel Company, the pressure suit and its accessories are checked for reliability.

protect various parts of the attitude control system.

The "Cockpit"

The pilot rests on a couch individually contoured to his shape, just over the baseplate of the truncated cone. With his left hand he can ignite the ejection rockets, cause the cabin pressure to drop sharply (to put out a fire) or switch on pressurization again. His right hand rests on a console with switches for the life support system. He can, for instance, regulate cabin temperatures between 50 °F and 90 °F, or actuate the attitude control column. Certain important data, such as attitude in space, acceleration, rate of descent, altitude and fuel supply are indicated on an instrument panel. Faulty operation of the satellite systems is indicated by red lamps. For orientation in space, the pilot has a rectangular window and a periscope at his disposal. The latter, developed by Perkin-Elmer, has a lens which extends at the beginning of the unpowered phase and a screen 24 inches in front of the pilot. At its "high" setting, the periscope can "see" a section of the earth's surface with a diameter of some 1,900 miles; in the "low" setting the field of view can be reduced to an area with a diameter of 80 miles. Altitude can be accurately determined to within ±10 nautical miles.

The schematic on page 799 shows the layout of the life support system. Here it should be remarked that the cabin "air" consists of pure oxygen. Air pressure is only 5 p.s.i., i.e. about a third of air pressure at sea level. The air conditioning installation is designed for an operating life of 32 hours.

The question of the oxygen supply meant considerable headaches for many sub-contractors. McDonnell specified that all equipment in the pressure cabin must be able to work satisfactorily in pure oxygen for 24 hours, without exuding malodorous or poisonous gases or creating the risk of fire or explosion—a requirement that caused the designers of the electrical equipment some severe problems. Relays and switches have a tendency to form sparks and must therefore be carefully insulated, as sparks form ozone, which in large quantities makes air unbreathable.

The boosters

In the absence of boosters designed specifically for space research, the Americans had to turn to guided missiles, which are being adapted for their

A *Redstone* carried the chimpanzee "Ham" to an altitude of 155 miles on January 31st. (*Left*) launching from Cape Canaveral. After four hours, the capsule was found floating in the Atlantic 420 miles from the launching site and recovered by helicopter. (*Upper picture*) Although the capsule was slightly damaged, the first *Mercury* pilot had stood up well to the flight, and joyfully snatched at an apple after the lid of his cabin had been removed (*below*).

The parachute equipment being installed. The outer covering has not yet been put on.

new application as best they can. The *Mercury* programme is no exception: for short ballistic flights the Army is supplying a number of *Redstone* rockets, while the USAF is contributing its *Atlas* ICBM for earth orbits.

It is to the *Redstone*, developed by Wernher von Braun and his team, that the Americans owe two names on their astronautical roll of honour: their first earth satellite, *Explorer I*, on January 31st, 1958 and their first astronaut on May 5th, 1961. To increase the powered phase—by 20 seconds—Chrysler technicians have lengthened the rocket by 6 ft to enable it to carry more propellant. With *Mercury* capsule and escape tower it measures 83 ft in length and weighs 66,000 lb. The Rocketdyne A-7 engine develops 78,000 lb thrust; propellants are alcohol and liquid oxygen. It goes without saying that many modifications were necessary to fit the *Redstone* for its momentous task of serving as a booster for a manned space vehicle. A warning system indicates any deviation from normal behaviour, at once cuts the rocket engine off and actuates the payload escape tower. The guidance system, developed mostly by the Ford Instrument Company, is considerably simpler than that of the guided missile version.

Even in the *Atlas*, certain modifications have been necessary. At the unsuccessful MA-1 launching in July, 1960, it transpired that there were violent vibrations in the nose section of the rocket. This resonance, caused by air forces acting on the capsule and booster in conjunction with engine vibration, was eliminated by reinforcing the external skin and the adaptor ring.

Safety first

The first design specification states that space flights in the *Mercury* capsule must not be more dangerous for the pilot than test flights with a conventional aircraft. As, however, there are many more danger factors in space flights—explosive boosters, high accelerations and thermal stresses, critical environmental conditions, re-entry, landing in remote regions—they must be compensated for by appropriate precautions.

Even before launching, the booster filled with propellant represents a danger to the astronaut in his capsule at its tip. A kind of grab, known as the "cherry picker," has therefore been developed, to lift the capsule from the rocket to safety if a fire is suspected or if there is danger of explosion.

In the event of faulty operation of the booster after launch, an ejection device is automatically actuated. First, explosive bolts release the capsule from the booster; next, three rockets mounted on a tower at the booster nose carry the capsule off to the side, out of the climb trajectory; finally, the capsule floats safely to earth on a ringsail parachute.

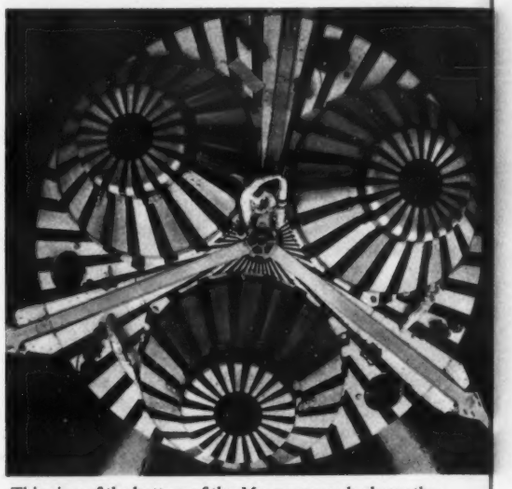
All the main systems are provided at least in duplicate, or there are other systems at hand to do their work. A so-called "if" study published by NASA makes it clear that immediate measures can be taken against every imaginable operational fault. The following are a few points selected from this document.

"If the spacecraft does not automatically separate from the launch vehicle at booster burnout, separation can be initiated by ground command or by the astronaut."

"If the automatic attitude control system does not orient the spacecraft to the proper retrorocket firing attitude, the astronaut in the cockpit can assume attitude control through one of two alternate control systems."

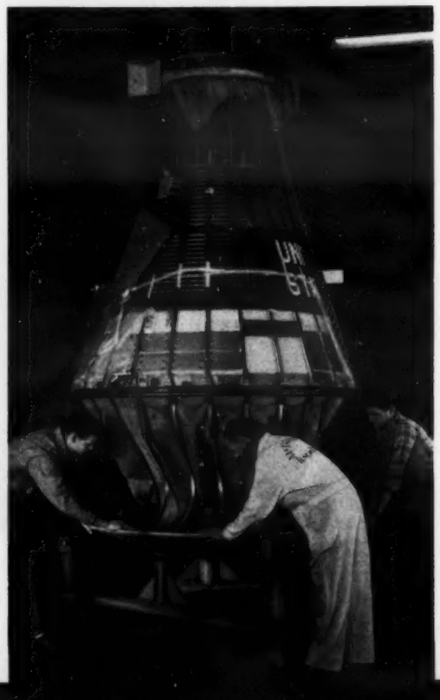
"If the main landing parachute does not deploy or open properly, at about 10,000 ft, a reserve landing parachute is available and can be deployed by the astronaut in the cockpit."

The landing and recovery devices alone are a masterpiece of engineering. Released by an aneroid barometer, a drogue 'chute opens after re-entry, at about 40,000 ft, to stabilize the capsule in attitude and decelerate its free fall speed from Mach 1 to 160 knots. At the same time, a packet of radar chaff is ejected, the radio beacon begins transmitting, and excess propellant is jettisoned. The main parachute unfolds at an altitude of 10,000 ft; this is a development of the Northrop Radioplane Division, which is responsible for the entire landing system. The parachute's high drag coefficient of 0.72 further decelerates it to a rate of descent of 30 ft/sec. At the same time, concertina-like bellows fill with air and form a cushion to soften the landing impact. If the capsule comes down in the water, a luminescent dye is released, which marks the position of the floating capsule. The latter can be easily found, as it transmits radio signals uninterruptedly and emits light signals at night. The pilot can leave it at any time by the entry hatch, the "neck" or an emergency exit which is opened by explosive bolts, and climb onto his life-raft.



This view of the bottom of the *Mercury* capsule shows the three braking rockets (here mock-ups), which will be fired either by the pilot, automatically or from the ground to initiate the descent trajectory in orbital flights. After burnout, the braking rockets separate from the capsule before it enters the denser layers of the atmosphere.

The heat sink being fitted to the last capsule to be tested (April 28th) before Alan Shepard's flight. During the test, a *Little Joe* solid-propellant rocket carried the capsule to a height of 12,000 ft, where the recovery device was actuated. The capsule came down in the Atlantic a few minutes later and was recovered. The concertina-shaped bellows automatically fill with air after the recovery parachute is released, and form a cushion which considerably softens the impact on the water.



Break tests for human beings

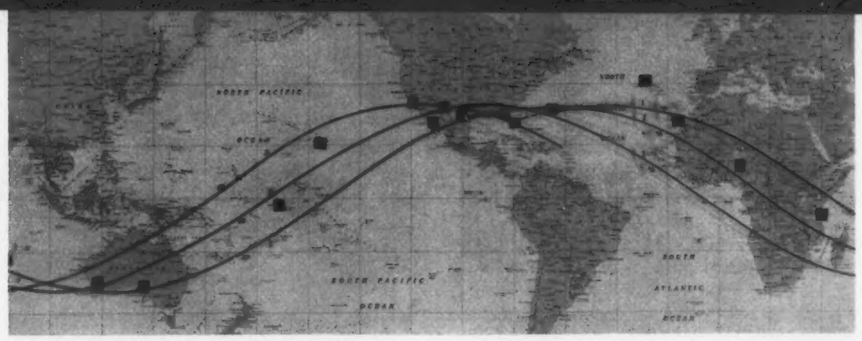
One day, the crew and passengers of a space vehicle may be subjected to physiological and psychological stresses scarcely greater than those experienced by the occupants of a passenger airliner today. But this day is still years, if not decades, ahead. At present, any space flight taxes man to the limit of his endurance. Indispensable prerequisites for the astronaut are physical and mental health, cool-headedness, reliable powers of judgment even in moments of extreme danger, the ability to take decisions, and quick reactions. Although both American and Soviet space vehicles are so designed that they can return safely to earth even with an unconscious occupant on board, situations may arise during any phase of the flight which require prompt and correct action on the part of the pilot.

A profession in which the above conditions must to a great extent be met is that of test pilot. Out of hundreds of applicants, a committee of doctors, psychologists and technicians finally chose the seven *Mercury* astronauts, details of

whose lives have been fully reported by press, radio and television all over the world. For the past two years, these seven men have been undergoing a severe training programme to prepare them systematically for the tasks and stresses awaiting them on their space flights.

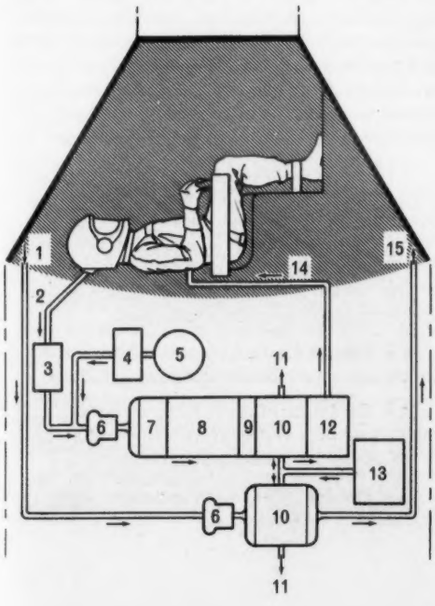
After theoretical courses in astro mechanics, ballistics and astro navigation and their application during *Mercury* flights, the pilots were familiarized with the capsule structure and instructed in the biological effects of various environmental conditions. This was followed by practice in leaving the floating capsule in heavy seas, with and without pressure suit. At a comprehensive course in the Nevada desert, the astronauts were trained in desert survival—in the event of the capsule making an unplanned descent in arid regions. Numerous flights in different aircraft types were made to familiarize the pilots with weightlessness during a ballistic trajectory; each of the seven *Mercury* pilots has spent over 40 minutes under such conditions. Tests on the U.S. Navy's large centrifuge at Johnsville, on which the astronauts were subjected to accelerations of 16 g, to a certain extent served the opposite purpose. During the tests they were required to repeatedly actuate controls and switches in a cockpit mockup at reduced air pressure. Tests in the *Mercury* simulator enabled practically all space flight conditions to be recreated, apart from accelerations. Two special simulators were used for training in orientation, during which the trainee had to orient himself to the correct attitude by means of "attitude stabilizer rockets."

John Glenn, Virgil Grissom and Alan Shepard, the three pilots short-listed to make the first flight, have been subjected to special psychological tests during recent months. For the simulation of a complete flight, the astronaut was fully dressed in his pressure suit and taken in a specially air-conditioned vehicle to the launching pad, where he entered the capsule. Next, the countdown was made, followed by a "flight" in the stationary capsule, during which certain operations were carried out according to a time schedule or telephoned instructions.



The seven *Mercury* astronauts in Cape Canaveral control centre, from which all flights can be monitored. The trajectory can be plotted on the wall map in the background, while the white panel and the various control consoles give continuous indication of the data telemetered from the capsule to the earth. The seven astronauts (left to right): Donald Slayton, Walter Schirra, Virgil Grissom, Alan Shepard, John Glenn, Scott Carpenter and Gordon Cooper. The map of the world shows the orbit planned for later flights. Under present plans, an astronaut is to be sent into orbit by the end of the year. Black rectangles mark observation stations.

The oxygen system for the Mercury capsule was developed by AiResearch Manufacturing Co., a Division of the Garrett Corporation. The schematic illustrated here is under the pilot's seat. 1 – from cabin; 2 – from suit; 3 – debris trap; 4 – pressure reducer; 5 – oxygen container; 6 – fan; 7 – odour absorber; 8 – carbon dioxide absorber; 9 – filter; 10 – heat exchanger; 11 – vent; 12 – water absorber; 13 – cooling tank; 14 – to suit; 15 – to cabin.



A network of ground stations

The Americans have set up a world-wide network of 18 ground stations to monitor the space flights. The prime contractor for the main equipment of the tracking and telemetry systems is the Western Electric Company, whose sub-contractors include Bendix, Burns & Roe and the International Business Machine Corporation. The Collins Radio Company is responsible for the radio equipment in the capsule.

At Cape Canaveral is the control centre, equipped by the Information Technology Division of General Dynamics. The position of the capsule is displayed on a wall map, while technical and biological data are indicated on wall panels and small control consoles. Two IBM 7090 electronic computers are available at the NASA Goddard Space Flight Center for the immediate evaluation of various data.

The future

The final aim of the *Mercury* programme is to orbit the earth three times in a manned capsule. Despite Alan Shepard's successful flight on May 5th, it is expected to be some months before a man will be sent into orbit from Cape Canaveral. At the end of June a second pilot—Glenn or Grissom—will make a short flight in a *Redstone* booster. A third attempt will be made in July. Although NASA still has four *Redstones* in hand, it is not thought likely that all four will be used. In any case, an unmanned capsule will first be sent around the earth, followed by a chimpanzee and perhaps by an astronaut towards the end of the year, provided the *Atlas* launchings proceed according to plan.

In recent years, the *Mercury* programme has come in for severe criticism. It has been argued that the pilots are nothing but live ballast and that the *Mercury* capsule offers no possibilities for further development. The advocates of the programme, on the other hand, claim that the *Mercury* flights are ideal for studying the behaviour of man under space flight conditions and determing what part he can play in later, more advanced space vehicles. Not least of all, *Mercury* is the most far advanced of all projects for manned spacecraft.

Be that as it may, the success of May 5th has given a powerful impetus to the whole of American space research and, perhaps more important, has encouraged the authorities to grant further funds. It is also certain that the $500 million which Project *Mercury* is expected to cost do not represent "money thrown down the drain." For the experience gained in capsule construction, in pilot training and finally in the flights themselves will be indispensable to future manned spacecraft developments such as *Apollo* and *Dyna-Soar*.

Does the USAF Need the Mach 3 Bomber?

By Colonel C. Tosti, Washington

Rarely have opinions on any military development in the past decade been as divided as on the B-70 supersonic bomber programme; rarely have the responsible planners been in such perplexity regarding the pros and cons; and rarely have the finance departments clung so tenaciously to their funds.

In the eyes of its advocates, the B-70 deterrent has excellent prospects of surviving an enemy offensive. Whatever may be its prospects of survival, however, it is at present having some difficulty even in coming to life—perhaps not surprisingly, for its development falls within a decade in which the intercontinental ballistic missile is affirming its supremacy.

This difficulty was in any case to be foreseen when the U.S. Air Force first sought a successor to the B-52 strategic bomber in 1954/55. Even then, development work was proceeding on the wide range of guided missiles which are now beginning to fill U.S. military arsenals. If, therefore, the competent USAF commands—Air Research and Development Command, Air Materiel Command and Strategic Air Command—nevertheless urged that a manned bomber should be developed, they had very good reasons for doing so, reasons which, as will be seen, have not lost their validity.

Admittedly, the weapon system projected at that time—which initially bore the designation 110A—had little in common with the B-70 of today. The first specifications demanded a cruising speed of no more than Mach 0.9 and "the maximum possible speed during a 1,000 nautical mile penetration."

The 110A weapon system project office set up at Wright Air Force Base at the beginning of April, 1955, submitted a report in July of that year, recommending that an initial wing of 30 bombers be commissioned in 1963. No less than twenty experimental aircraft were to be used for flight tests. The programme was thus begun in a liberal and energetic way—on paper.

The main contractors originally considered were Boeing and North American, who submitted designs which were so radically different from each other that the weapon system met with its first stoppage and the two companies were asked to "go back to the drawing board." Incidentally, according to the preliminary designs, all-up weights of almost 350 tons would have been necessary if the payload and range requirements were to be fulfilled; in one design, enormous panels filled with fuel were to be attached to the ends of the wings, for jettisoning after the fuel had been used up. To avoid unrealistic approaches of this kind, the use of high-energy fuels and boundary layer control was investigated, but these solutions were rejected when it was found, after comprehensive wind-tunnel tests, that the specifications could be met without such measures.

In July, 1957, North American and Boeing each made independent statements to the effect that the bomber would be able to fly at supersonic speed throughout its mission. In mid-December, 1957, North American was awarded the contract for the weapon system, with General Electric as associate contractor for the engine. Since this first start the B-70 weapon system has been hovering between life and death.

At the end of 1959 the USAF announced that production was being halted, and only a single experimental prototype would be built. The prospects for the weapon system looked blacker from one year to the next: the appropriation for the fiscal year 1960 was cut from $345.6 million to $150 million, and by 1961 the appropriation had dwindled to $75 million.

Subsequently, the Eisenhower Administration decided to increase the development appropriations by "dribs and drabs," one of its reasons for doing so possibly being that it was not fully confident of the accuracy of the ICBM. In addition, with the creation of a fleet of strategic bombers the USA hoped to force the Soviet Union into setting up a vast defence organization. Not least of all, this partial change of heart on the part of the Government was influenced by a report of the Preparedness Investigating Subcommittee of the U.S. Senate Committee on Armed Services, on whose findings the following article by Colonel Tosti is based.

The Kennedy Administration does not, however, appear to have been influenced by the conclusions reached by the Subcommittee, for in the 1962 draft budget it has reduced the appropriation for the weapon system from $360 million to $220 million, announcing that only $1,300 million are to be spent on the whole programme instead of the $2,700 million originally envisaged.

This decision—which is hardly expected to be final—appears to indicate, despite official denials, that budgetary preoccupations were the main consideration in the "go-slow" on the B-70 programme. It is not the place of *Interavia* to discuss either the USA's financial difficulties or its strategic requirements. If it opens its columns to the B-70 programme, this is only because it feels that this development can make valuable contributions to technological progress in both the military and civil sectors. *Editors.*

For the past several years, world attention has concentrated on developments in space. The ballistic missile, during this time, has emerged as a formidable weapon offering advantages of high survivability, quick reaction and effective and accurate nuclear weapon delivery. The natural question has been "Will manned bombers be needed in the future?" More precisely, the question generally asked is "Does the United States need a *new* manned bomber to replace, or follow, the B-52?" Usually, this question has arisen when discussing the USAF B-70—a supersonic bomber to be capable of flight at a speed of 2,000 m.p.h.

You may wonder why I, a "missile man," undertake to discuss the B-70 and to endorse it as a much-needed manned weapon system development. The answer is simple. I realize, as all of us must realize, that the ballistic missile—while dramatic and effective—cannot serve all the needs of deterrence and security. In this article, I propose to point out the desirable characteristics of a manned bomber, in particular the B-70, and how it complements the ballistic missiles in providing a well-rounded strategic force during the 1965-1975 time period.

In 1955, the Air Force established the requirement for a follow-on manned weapon system to the B-52; this manned bomber requirement gave birth to the B-70. From 1955 to 1959, about $325 million were invested in this development program. In December 1959, budgetary problems caused the program to be cut back from a weapon system to a test vehicle "prototype" development. Champions of a new manned weapon system came to the fore, and the attention of the public and of Congress was focussed on the question of whether or not an advanced manned bomber will be needed in the so-called "missile age." A discussion of the need for both airplanes and missiles generally leads to an affirmation of the "mixed force concept."

This concept has been stated often by Air Force and industry leaders. Lt. Gen. B. A. Schriever, Commander of the Air Research and Development Command and perhaps the outstanding "missile man" in the free world, referred to it in these words:

"My own feeling is, and it is very strong, that we must maintain manned aircraft in our retaliatory force as well. Now, the exact mix of missiles and aircraft will have to be constantly studied. But you need, first of all, the flexibility of an aircraft and a man in it—you can never put all your eggs in one basket. You have to have a diversified capability in this job of deterring total war."

With the developments of late 1959 and early 1960, which cut back development funds, the stage was set for a Congressional "look-see" into the B-70 program. The Preparedness Investigating Sub-Committee of the Armed Services Committee of the United States Senate conducted a study and reported these main conclusions:

"1 – There is a need for a manned bomber with supersonic speed and intercontinental range.

"2 – The advent of the ICBM does not preclude the necessity for continued development and use of an advanced manned weapon system.

"3 – The Nation has the necessary resources to build the B-70.

The North American B-70 *Valkyrie* supersonic bomber would be able to operate from existing runways at SAC bases.

"4 – The technology required to build the weapon system is at hand and is not dependent upon a technological breakthrough."

The need for the B-70, consequently, was reaffirmed by the Department of Defense, and late in 1960 funds were restored, raising the FY 1961 budget to $265 million. First flight of the XB-70 is planned for late 1962 with the weapon system prototype to be completed later.

What is the B-70?

The B-70 is a high-altitude, Mach 3 manned weapon system—*all the way!* While this appears to be an extremely taxing performance regime, engineering studies conducted in arriving at the B-70 design indicated that if the entire aircraft—the jet engines, the air induction system and the airframe—were optimized for the single flight condition of continuous Mach 3 cruise, its range would compare to that of an airplane designed for subsonic cruise and Mach 3 dash. This supersonic design was made possible by certain engineering breakthroughs—principal among these being that of compression lift. This principle has been compared to the effect achieved when a speedboat gets up "on the step." The impact of this finding by scientists of the National Advisory Committee for Aeronautics (NACA) was described by Dr. Hugh L. Dryden, Director of NACA, in February 1958:

"A year or so ago, the Air Force was reconciled to the idea that the best it could obtain in the way of performance from such a new large bomber would be what the engineers call high subsonic cruise plus supersonic dash, similar to the B-58. About a year ago, a strange and wonderful thing happened. It was as if the pieces of a jigsaw puzzle began falling into place. Almost simultaneously, research programs that had been underway at the NACA labs in Virginia, California, and Ohio began to pay off. The result—this is an oversimplification, but it is not an overstatement—was that the companies and the Air Force suddenly realized it would not be much harder to design a long-range bomber that could fly its whole mission supersonic than to design one that would fly subsonic most of the way, and only a small fraction of the flight supersonic. Not only that, but the top speed of the prospective bomber was raised to Mach 3, about 2,000 miles per hour."

The application of this new knowledge resulted in the present B-70 configuration. The B-70 is a large delta-wing aircraft with a forward horizontal stabilizer or canard. While radically different than the B-52 in design, it is of the same order in size. Although it is about 10 percent heavier and somewhat longer than the B-52, its wing span is much narrower. New airfields need not be built, since the B-70 will be able to take off and land on those used by the B-52 bomber force.

Propulsion in the Mach 3 regime will be provided by six turbojet engines. These will be the J-93 engines with afterburners which are being developed by the General Electric Company. The power delivered by this propulsive system is estimated to be several times that of the new B-58 intercontinental bomber (Mach 2 dash capability).

The six turbojet engines are located to the rear, as are the bomb bay and landing gear. Air reaches the engines through specially designed ducts. Fuel is carried in the wings and parts of the fuselage.

Because of the high speed of flight over the entire flight profile, aerodynamic heating will be a major problem. In some places on the airframe, temperatures will be hot enough to broil steaks —550°F. Structural problems therefore, are particularly challenging. To withstand the stringent flight conditions anticipated, most of the external surfaces of the airframe will be of a honeycomb sandwich construction using high-strength stainless steel. This type of structure offers a high strength-to-weight ratio and adequate fuel insulation. Also high-strength, heat-resisting titanium alloys are used wherever a weight saving can be made without sacrificing structural integrity. The techniques of using steel and titanium structures are not new to the industry of North America, since they have been used in the construction of the F-100, the *Navaho* missile and the X-15 research vehicle.

As an operational weapon system, the B-70 is designed to have a flight crew of four—the pilot, the co-pilot, the bombardier-navigator and the defense operator. The crew of the B-52, by comparison, consists of six officers and airmen.

From the standpoint of human factors, the B-70 is a milestone in aircraft progress. The forward compartment of the fuselage not only houses the large array of electronics equipment essential to the operation of the weapon system, but also is pressurized and air conditioned to allow the crew to work comfortably.

While operating at near-vacuum altitudes of 70,000 feet, crew members—aircraft commander, co-pilot, bombardier-navigator and defense system operator—can fly in their shirt sleeves in an airliner type environment.

In an emergency, crew members' seats will convert into capsules which permit them to take the airplane to lower altitudes, where they can survive without the capsule's protection. If forced to leave the plane, the encapsulated crew members would be rocketed through escape hatches.

Safe ejection can occur under operational conditions ranging from take-off to flight at 2,000 miles per hour at 70,000 feet.

The encapsulated seats have clam-type doors that snap shut from the bottom and top to provide an airtight seal. This eliminates the need for an oxygen mask or pressurized flying suit. Once clear of the airplane, the capsule is lowered to the earth by a 34-foot nylon parachute. Landing shock is absorbed by a large gas-filled rubber bag on the bottom of the seat.

More than 60 actual parachute drops have been made in tests near the Salton Sea, which prove the feasibility of the new seat system.

Should the landing occur in calm water, the capsule floats with the doors open. In the event of stormy seas, the capsule would remain closed and float indefinitely. A pop-up radio antenna enables the crewman to transmit distress signals any time he desires.

More than 45 pounds of survival gear are packed beneath the seat providing protection against Arctic cold or desert heat. Fishing tackle, a hunting rifle, first aid equipment, and supplies of food and water also are part of the survival gear carried.

What will it do?

Undoubtedly, the B-70 will be an airplane of exceptional performance as regards speed and altitude. But what need will it serve as a supersonic manned weapon system?

The B-70 was designed to serve the U.S. policy of deterrence through strength. In the B-70, the objective is to provide a secure, quick-reaction, recallable weapon with an operational capability tailored to the particular military or political situation existing at any time. In its versatility, it will be able to carry any type of modern, airborne weapon and many different combinations of weapons, including both nuclear and conventional high explosives.

Its intercontinental range of over 7,000 nautical miles and cruising speeds of 2,000 miles per hour place the B-70 within a few hours of any point on earth while operating from within the continental United States.

With its quick reaction capability, the B-70 can get off the ground and be on its way to distant

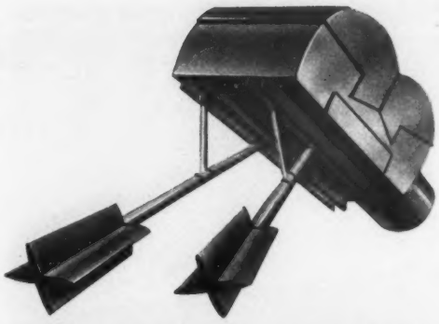
targets well within the 15 minutes of warning against nuclear ballistic missile attack to be provided by the long range radars of the Ballistic Missile Early Warning System (BMEWS)—a system which will be going into full operation soon. During the operational time period of the B-70, the *Midas* satellites—Missile Defense Alarm System—will probably become operational and will detect enemy missiles as they leave the earth's atmosphere immediately after launch. This system will provide almost twice the warning time attainable with BMEWS and will further enhance the survivability and retaliatory capabilities of the B-70.

As to survival on penetration over enemy land areas and targets, the speed, altitude, maneuverability and flexibility of penetration routes available to the B-70 will greatly assist it in successfully delivering its weapon load and returning safely. Penetration survival will be further enhanced by the ability of the defensive sub-system to confuse enemy defenses with electronic countermeasures and decoys. To defend against such a weapon system as the B-70, therefore, an enemy would be forced to invest heavily, not only in the development of a new family of defensive weapons, but also in the complex ground environment essential to their operation and control.

But the value of the B-70 transcends that of a nuclear weapons delivery vehicle alone. A special capability could be that of surveillance over any tactical situation as might be encountered in either general or limited wars. Further, since it can be flown over friendly territory and on the perimeter of nations which threaten peace, it serves to reassure our allies and friendly nations of American support and strength. Also, in the event of war which is limited in scope, the B-70 can be utilized effectively to deliver non-nuclear weapons. In short, the B-70 is a very versatile weapon system.

A major advantage of a manned bomber such as the B-70 over long-range ballistic missiles is that of accuracy. Even though the accuracy of ICBMs such as the *Atlas* is much better than originally anticipated and has been described as being within a runway length of a target, the accuracy of the bomber-delivered weapon is even more precise. In a manned bomber, the bombardier can sight directly—whether optically or electronically—on the target; he can correct all accumulated navigation errors and map or geodetic errors; then he can release the weapon at comparatively short range.

The bombing and navigation system of the B-70 will embody the finest inertial navigation techniques and radar-sighting equipment to achieve extremely accurate route control and bomb delivery.



The seat of each crew member is enclosed in a recovery capsule with a clamshell-like protective hood. This will enable its occupant to be ejected from the aircraft and brought safely back to earth by parachute. The capsule is fitted with two folding tubes with cruciform fins to stabilize it immediately after ejection. The gas-filled cylindrical bag underneath absorbs the landing shock.

Although the B-70 in itself is an impressive offensive weapon system as I have described it, it has the possibility for even greater versatility and swift weapons delivery when armed with air-to-surface weapons of the *Skybolt* type—an air-launched ballistic missile. On airborne alert, a weapon system combination of the B-70/*Skybolt* type offers the advantages of great mobility, high survivability and quick reaction, since it combines the Mach 3 speed of the airplane with the hypersonic speed of the ballistic missile.

Other applications

The B-70 and the advanced technology which it is producing offer other possibilities. While not a part of present Air Force plans, the B-70 makes possible the development of a long-range interceptor for the air defense mission. Should such a long-range weapon be required in the future, the B-70 will have sponsored the development of scientific and technical knowledge required to produce such a weapon system. Armed with long-range guided aircraft rockets like the GAR-9, an advanced member of the *Falcon* family built by the Hughes Aircraft Company, such a weapon system would provide an effective defense against the manned bomber.

The B-70, furthermore, will be useful for more than purely weapon delivery purposes. For one thing, its development will contribute valuably to the development of supersonic transports, both military and commercial. A transport modeled on the B-70 could carry 80 first class or 108 tourist class passengers. Cargo versions could deliver a payload of 75,000 pounds over a range of 2,470 nautical miles (over 2,800 statute miles).

As a commercial airliner, the supersonic transport version of the B-70 would take the following flight times from "wheels off" to "wheels on" plus 15 minutes:

New York to Paris	2 h 25 min
Los Angeles to New York	1 h 40 min.

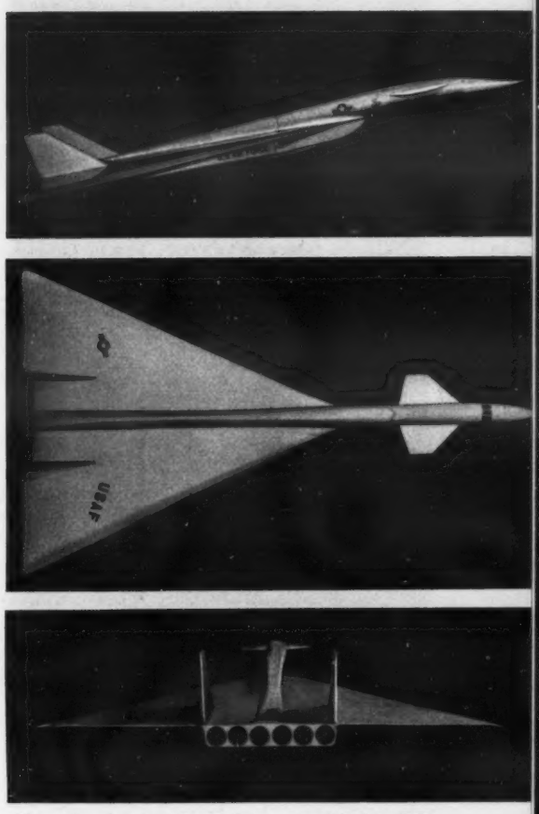
The B-70 also has possibilities for use as a recoverable booster for space vehicles—both military and scientific. The launching of space vehicles is very expensive. The cost of the first stage booster represents a large percentage of the launching cost. Studies with the B-70 have indicated that it will be possible, if so desired, to adapt the B-70 as a recoverable first stage booster system operating at speeds of 2,000 miles per hour and at altitudes of about 70,000 feet, from which payloads such as scientific space probes, military earth satellites like *Midas* and *Samos* and satellite inspectors can be launched and injected into orbit. Considering the large number of space launches predicted for the 1965 to 1980 time period, a very large dollar saving is possible through the application of such a technique. In any case, it is a possibility not to be overlooked in future planning.

As yet, the B-70 is at an early stage of development. Whatever may be its future, there can be no doubt that it represents an important contribution to progress in manned flight. In this respect, its name will be added to the list of major research programmes—such as the 4,000 m.p.h. X-15 research aircraft or the 15,000 m.p.h. *Dyna-Soar* space glider. These research vehicles will extend man's capability of flight not only to higher speeds, but also to higher altitudes beyond the salutary environment of the earth's atmosphere. It is most important today, therefore, to move swiftly into the future with the B-70. ←←

A model of the B-70 supersonic bomber on the control console of the IBM 7090 computer, which is playing a decisive role in the development of the bomber. The IBM computers have solved all the imaginable operational problems of the B-70 and enabled a wide variety of missions to be simulated in over 13,000 hours of calculations.

The Technical Significance of the North American B-70 Valkyrie

By Interavia Study Group



Three-view drawing of a wind-tunnel model of the B-70.

In view of military secrecy requirements, it is still not yet possible to give a detailed description of the 250 ton B-70 supersonic bomber. The external configuration, which alone could provide the subject for a whole article, is shown in the illustrations.

The most striking external features of the bomber are the stabilizing surface, which is at the front of the fuselage, and the double fin over the wing; this configuration is dictated by stability requirements for supersonic flight. The stabilizing surface is all-moving and thus serves to trim the aircraft in various flight conditions, As, for stability reasons, delta-wing aircraft cannot normally be fitted with landing flaps (extension of the flaps at the wing trailing edge would cause nose-heaviness), the problem has been solved by fitting additional high-lift flaps to the stabilizing surface in front; this means that the elevons can be used as flaps. This new "double-flap" system gives such high lift coefficients that the B-70 can take off and land at relatively low speeds on existing runways at SAC bases.

At the same time, care was taken to ensure that the delta wing was adapted to flow conditions over the entire speed range, i. e. both to Mach 3 cruise at 70,000 ft and to low-level subsonic flight (for refuelling by KC-135 jet aircraft).

In the fuselage rear are installed the six General Electric J93-3 engines, each delivering 33,000 lb thrust, whose common air intake extends to the centre of the fuselage. The development of the engines, which were originally designed for the North American F-108 interceptor, now abandoned, is about a year in advance of that of the rest of the B-70 airframe and its equipment. A number of J93s have for some time been undergoing tests on the General Electric Company rigs at Evendale, Ohio.

The design of the air intake system required particular care, as it has a decisive effect on the specific fuel consumption and hence the range. Ram air pressure, which is considerable at Mach 3 flight, had to be made use of, as far as possible without dissipation, to raise the compression ratio of the entire propulsive system (engine intake and compressors). Shock-wave variations or choking in the intake constitute a serious danger, not only to the engine (breakage of compressor blades), but to the aircraft as a whole. For the resultant thrust fluctuations in individual engines cause asymmetrical thrust forces and hence yawing of the whole aircraft, which in Mach 3 flight can lead to breakage of the airframe. By mounting all the engines together in a single nacelle in the fuselage rear, the danger of asymmetrical thrust is to a great extent reduced. Special devices serve to dampen transients and prevent choking of the intake. The B-70 intake system is so designed that if one engine fails the airflow to the remaining engines continues unimpeded. "Under some circumstances," says a report by the Committee on Armed Services of the U.S. Senate," ... the B-70 will be able to continue [its mission] with very slight degradation in performance."

In the fuselage rear, just in front of the engines, are the bomb bay, almost 30 ft long, and the landing gear. The former can accommodate all nuclear weapons and non-nuclear bombs, or special drones to act as decoys or enemy radars. The bomb bay can also carry a set of ECM equipment for jamming the enemy's radar defences.

The air conditioning of the crew cabin and the electronic equipment makes very severe demands, for at Mach 3 the entire airframe is heated to such an extent that both crew and electronic equipment require artificial cooling and a continuous change of air. The cool air flows in through ducts in the pressurized crew cabin and leaves through porous surfaces in the cabin wall. The internal cabin pressure (8,000 ft pressure altitude at flight altitudes of 70,000 ft and above) is maintained by using the high ram pressure reinforced by additional compressors. If the pressurization system fails or the cabin walls are damaged, a further ram air unit leads large masses of fresh air into the cabin. In this case, however, the crew would have to wear oxygen masks.

The development of the main airborne systems of the B-70 was, as already mentioned, suspended in December, 1959, under the Eisenhower administration, but resumed in fiscal 1960/61; now it has again been halted by the Kennedy Administration. Construction at the present time is presumably limited to a few experimental aircraft with incomplete armament and equipment, and the future of the various systems is for the time being uncertain. It is nevertheless of interest to list the developments which have so far been made, since they might play a part in future programmes.

In the design of the IBM *bombing and navigation system,* literally all the teething troubles of similar systems so far developed have been eliminated. With automatic celestial navigation, special computers for a continuous comparison of position with the pre-programmed flight plan, a search radar with a screen to display the terrain overflown with photographic accuracy, new doppler procedures etc., the IBM system is the most modern and versatile ever to be installed in a bomber.

The *defensive subsystem* developed by Westinghouse serves almost exclusively for passive defence against enemy radar detection and rocket launchings, though the high speed of the B-70 in itself increases the difficulty of combating it with conventional interceptors and anti-aircraft rockets. The defensive subsystem enables the aircraft to perform voluntary evasive manoeuvres without affecting its mission. The defensive subsystem operator follows the data supplied by radar and infra-red sensors on visual displays, which give him continuous warning of whether the bomber is within enemy radar coverage, or of the approach of anti-aircraft and air-to-air missiles. He himself can lead the enemy's air defence astray by actuating a variety of jamming transmitters with a number of different modes and frequencies. In addition, he can divert enemy anti-aircraft and air-to-air missiles with infra-red homing heads away from the bomber, and launch decoys. The entire defensive subsystem of the B-70 serves to delay effective air defence measures by the enemy as long as possible. Even if this is successful for only two minutes, the bomber will have penetrated a further 60 miles into enemy airspace.

Air-to-ground and air-to-air radio communications, navigation, identification and automatic landing are combined in a complex system, developed by Motorola and designated AN/ASQ-43, which is known as MTC (Mission and Traffic Control System). The speed and range of the B-70 make it impossible to maintain radio communications with the ground or with other aircraft on frequencies which require a line-of-sight propagation of radio waves. It was therefore necessary to develop a long-range system for the transmission of voice radio and teleprinter communications to enable the aircraft to be directed and, if necessary, recalled from the SAC centre in Omaha. Finally, the B-70 was to be fitted with special equipment to enable it to track and destroy targets whose existence would be unknown on the outbreak of hostilities (e. g. highly camouflaged rocket bases).

*

Whatever may be the Pentagon's further plans for the B-70, aircraft construction techniques will have made great strides forward with the interim construction and testing of a few "aerodynamic prototypes." And nearly 10,000 concerns in the American aircraft industry, which have so far been working on the B-70 programme, will have gained a wealth of new experience. ⟶

Bristol T.188

Supersonic Research Vehicle

The chief test pilot of Bristol Aircraft Ltd., Godfrey Auty, who will pilot the T. 188 research aircraft on its first flight later this year.

At the beginning of May 1961, the British Aircraft Corporation announced that construction of the Bristol T.188 supersonic research aircraft had been completed, and that preparations for engine runs were in hand.

During the years that have elapsed since 1954, when the T.188 design team was formed at Bristol, fluctuations in Government and military policy have affected the role of the T.188.

The aircraft was originally intended for research into high speed aerodynamics, propulsion systems, and structures, with a view to future military requirements. Changes in military planning policy have modified these original aims somewhat, and the aircraft can now be regarded as a pure research vehicle for examination of the constructional and design problems involved in the development of a Mach 3 aircraft.

Previous articles in *Interavia* have given details concerning the wing planform, engine layout and construction materials employed.* In the first phases of the design of the T.188, much of the total effort was devoted to structural development work. The choice of stainless steel for the construction of the aircraft presented two problems. The first was the development of materials with the necessary structural properties, and to ensure their availability in reasonably large sizes of sheet of a higher standard of flatness, surface finish and accuracy than is normally demanded for commercial applications. The second problem was the development of fabrication techniques for the welding, jointing and fastening used in the construction of the aircraft.

The existence of the completed aircraft is evidence that these two problems were overcome, and in this respect the T.188 programme has produced its first tangible success before the aircraft has flown. Two new types of stainless steel were perfected in the course of the materials research programme, but were not available in time for incorporation in the aircraft. In consequence, any later Mach 3 project will have the benefit of this metallurgy research at the outset.

As is to be expected of an aircraft of this nature, the flying programme will be carried out in progressive stages. Once the basic flying qualities and handling characteristics of the aircraft have been proven, flight speeds will be advanced by stages from low speeds to transonic and, ultimately, supersonic speeds.

The fact that the aircraft will be capable of taking off under its own power will considerably simplify this programme. The system of air-launching supersonic aircraft from parent aeroplanes reduces the design complexity of the research vehicle but also reduces the flexibility in application.

For take-off and landing, the T.188 is equipped with a conventional tricycle undercarriage, and one detail in this connection illustrates the variety of problems that had to be overcome by the design staff. When flying at the upper limit of its speed range, even in the intense cold of the upper atmosphere, the outside of the T.188 is subjected to temperatures of up to 280° Centigrade. Aircraft tyres, although retracted into the wheel wells, would deteriorate at these temperatures and render landing hazardous. To eliminate the necessity for special refrigeration in the wheel wells, the Goodyear Tire and Rubber Co. has developed special "thermal" tyres which will withstand these temperatures without deterioration.

Not all the equipment carried in the T.188 can, however, be built to withstand the wide range of working temperatures encountered in high speed flight. A high capacity refrigeration system has been installed to protect the pilot and the extensive instrumentation against intense heat. A variety of measures have been adopted for equipment cooling since air cooling is impossible because the external air is hot. Using the aircraft's own fuel as a coolant and boiling off stored water are two methods which have been employed to make conditions tolerable. As a result the electrical, hydraulic, and power control components developed for the T.188 are capable of general application in future supersonic aircraft.

The completed T. 188 after roll-out from the production line. The aircraft is now undergoing a period of pre-flight trials and engine runs prior to its first flight.

* See Interavia No. 1, 1960, p. 102 and No. 9, 1960, p. 1159

As the T.188 has been designed as a test vehicle and information gained from the flight trials will have wider application than merely improving the design of the aircraft itself, its configuration has been dictated by the varied research roles it will be called upon to fulfil. The installation of the two de Havilland *Gyron Junior DGJ.10* engines in nacelles, mounted centrally on the wing, facilitates the changes in air intakes, engines or exhaust nozzles necessary for propulsion research.

As supersonic speeds increase, the efficiency of the turbojet engine depends to an increasing extent upon the efficiency of the air intake, and developments are already in hand which will explore the performance of intake shapes matched to the existing engines but representative of trends in design for supersonic projects. The use of separate, wing-mounted nacelles also makes possible, by suitable disposition, a substantial reduction of drag at supersonic speeds by inducing favourable shock wave interaction between the fuselage and nacelles.

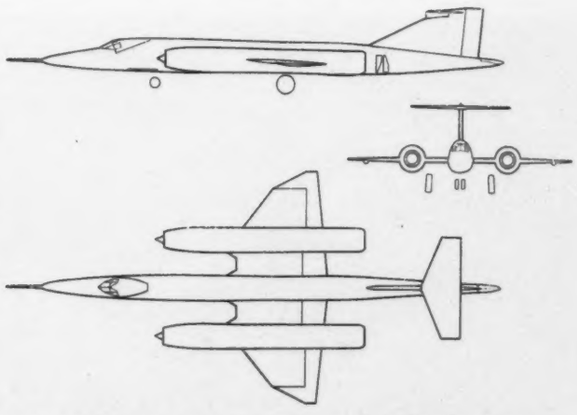
To ensure that the maximum amount of information is obtained from each flight, a comprehensive load of instrumentation is carried on board to record both the behaviour of the aircraft itself in flight and the conditions in which it flies. Some information will be recorded and stored in the aircraft for later examination and analysis; other data will be telemetered to the ground while the flight is in progress and recorded for later interpretation and analysis.

Apart from the information which will be derived from the future flying programme, the development of the aircraft to date has yielded much information of value which will be invaluable to the builder of a Mach 3 aircraft. An extensive series of wind tunnel trials has already been carried out, involving some 20 models of the T.188, covering both subsonic aerodynamic and aeroelastic problems. A further programme of free flight flutter testing was undertaken with models built around solid fuel rocket boosters. Information from these free flight models was telemetered to the ground by a telemetry system developed by the Guided Weapons Department of Bristol Aircraft Ltd. Ground tests have also been carried out during the past twelve months on a full-scale T.188 airframe at the Royal Aircraft Establishment, Farnborough. The information gained from these tests, when compared with observations of loads and temperatures in flight, will verify the design techniques.

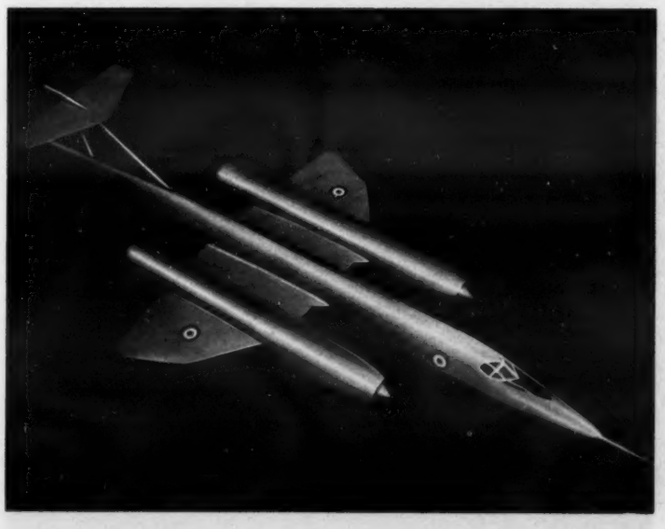
As the actual flight trials progress, and the T.188 reaches the upper limits of its design performance, it will enable many accepted theories of aerodynamics to be tested in the only satisfactory way—namely by practical experience. Much time was lost to the British aircraft industry when the problem of the sonic barrier was first encountered, and it was restricted to carrying out research with unmanned vehicles. At present the actual flying time which has been completed throughout the world at speeds above Mach 2 can be totalled in minutes. The existence of a research vehicle which will be capable of sustained flight at high supersonic speed will be an invaluable ally in the attack on the thermal barrier.

The progress of the T.188 trials will be watched with interest by aircraft manufacturing countries throughout the world. To a great extent, these trials will dictate the performance of the coming supersonic jet transport. ◆◆

A technician checks the cabling in one of the engine nacelles. The nacelles, which are fabricated from stainless steel, are fractionally larger than the fuselage in diameter.



A three-view drawing of the Bristol T.188. Two de Havilland *Gyron Junior* engines with reheat have been selected to power the aircraft.

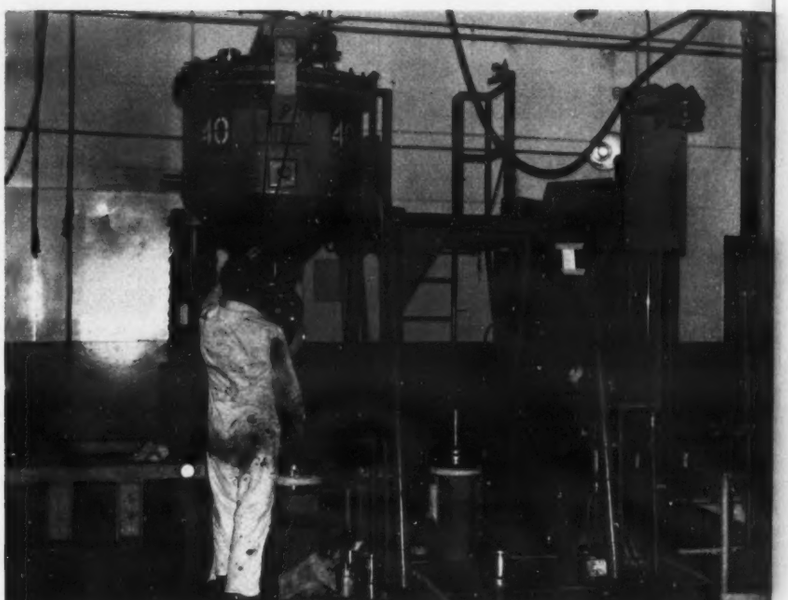


The configuration of the T.188 is illustrated by this model. The slight waisting of the fuselage is revealed in the photograph. ▶

Rocket Motor Production for the Tartar

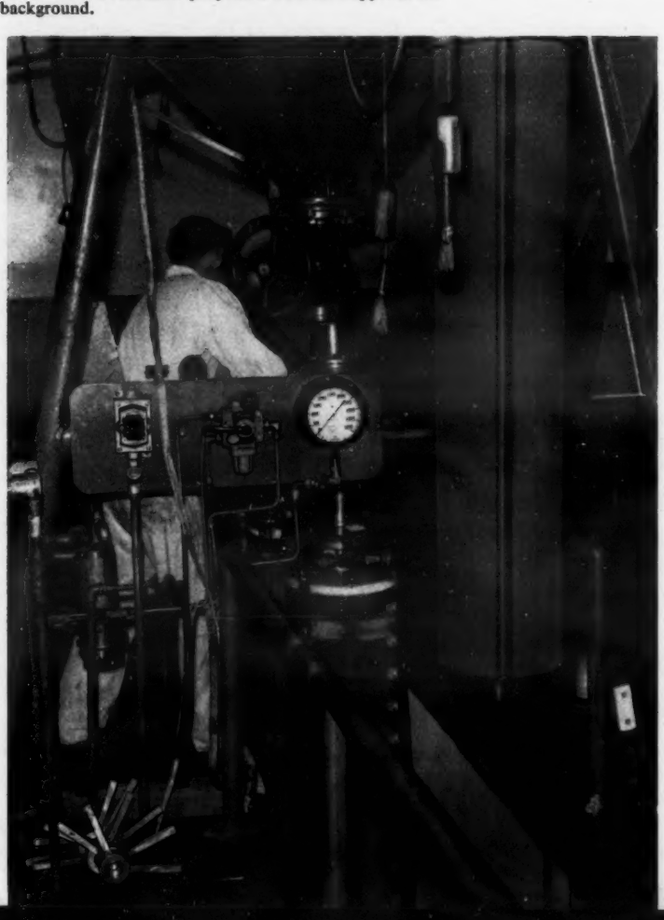
The first stage in the displacement casting method of producing the bi-propellant, dual thrust motor for the *Tartar*. The booster propellant or grain is cast in a vertical mould and allowed to harden.

After hardening, the booster grain is removed from the mould with the core still intact. The grain is then weighed and inspected for imperfections and to ensure that all the wax, used to coat the interior of the mould, has been removed.



The sustainer propellant, in a viscous condition, is poured into the rocket chamber. A special gauge device serves to ensure that the precise quantity is inserted. It goes without saying that, in all parts of the plant where propellants are processed, temperature and humidity must be kept constant within narrow limits.

The hardened booster propellant is hoisted by an hydraulic ram above the casting bay. The rocket chamber has just been filled with sustainer propellant from the hopper in the background.



After curing, the dual thrust grain is trimmed after removal of the central core.

The *Tartar* missile is a surface-to-air-defence weapon capable of intercepting and destroying enemy aircraft and missiles. Up to the present, the U.S. Navy has launched two guided missile destroyers which will be equipped with the *Tartar*. These two vessels are the USS John King, which was commissioned on February 4th, 1960, and the USS Charles F. Adams, which was launched in 1959.

The development and production of the solid rocket propulsion system for the *Tartar* is a cooperative effort between the Naval Weapons Plant in Washington D.C. and the Aerojet-General Corporation, Sacramento, Calif. The Naval Weapons Plant supplies the metal parts that are fabricated to the drawings and specifications prepared by Aerojet for the Bureau of Naval Weapons.

The problem of achieving the required ballistic performance of the missile, because of the dimensional limitations, presented many difficulties. These were finally overcome by the development of a bi-propellant, dual thrust grain which first operates as a booster and, after a few seconds duration, as a sustainer propulsion unit. These *Tartar* units were the first rocket motors which demonstrated that two propellant grains of vastly different ballistic performance could be built into a single pressure chamber.

The main problems confronting the engineers in the development of the propulsion system can be summarized under three headings. The first was the determination of a satisfactory method of casting the bi-propellant grain to achieve a suitable bond between the booster and sustainer propellants, and satisfactory bonding between sustainer propellant, chamber liner and chamber wall. The second problem was the selection of compatible propellants, and the design of a configuration which would provide the desired ballistic performance.

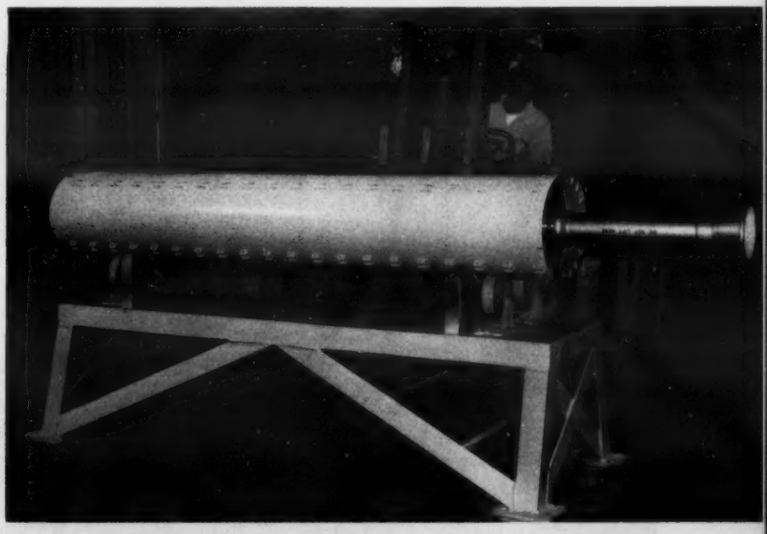
The third, and perhaps most difficult, requirement was the development of the nozzle extension tube. This extension tube was required because the design of the missile called for space at the aft end for the location of several important components, and precluded the possibility of locating the exhaust nozzle directly at the aft end of the motor. Extension tubes for rockets had been designed before, but none had been designed for the extreme heat environment that would be encountered during the *Tartar* motor operation. The tube would have to be capable of withstanding the severe erosive action of the propellant exhaust gases and also remain within the thermal limits demanded by the component space around the extension.

The filled rocket chamber containing the two grains is placed in the curing room.

The booster grain is forced hydraulically into the viscous sustainer grain. Great accuracy is required to ensure that the booster grain is centrally positioned in the rocket chamber.

In the final assembly, the aft closure, extension tube and expansion nozzle are fitted to the base of the *Tartar* rocket motor. The long extension tube is required to allow room for the installation of other components.

The completed motor prior to loading in a special container for despatch to a Naval Depot. At the Depot the guidance system components will be installed.



A satisfactory method of casting the bi-propellant grain was achieved by a new technique termed "displacement casting." The project engineers and tool design specialists of the Aerojet Rocket Manufacturing Division were called upon to design and fabricate special tooling, which was first used in the development phase and later in the production phase of the programme. One of the main problems encountered in this casting process was to ensure that the booster grain was centred exactly in the middle of the forward end of the motor. Any misalignment of this grain would result in erratic missile performance on firing.

The accompanying pictures display the main stages in *Tartar* production in chronological sequence. The hardened booster grain is seen positioned on a hydraulic ram, prior to being forced into the viscous mass of the sustainer propellant. This displacement casting ensures the satisfactory bonding between both the propellants and the rocket chamber wall.

The successful solution to the problem of combining two propellant grains of differing ballistic performance has been accompanied by improvements to the missile performance. Two types of *Tartar* missile propulsion units are now in existence: the Basic and the Improved *Tartar* rocket motors. Both have the same length and diameter, and both incorporate bi-propellant grains.

Work on the Basic motor began in 1956, and after development, flight testing and engineering testing, the motor went into production in March 1960. This production will be phased out in 1961, when the Improved motor, which started development in 1959, will enter the production phase. The Improved *Tartar* motor uses newly-developed high energy propellants which increase performance during the sustainer phase by about 25 percent, giving the missile greater range and increased altitude performance.

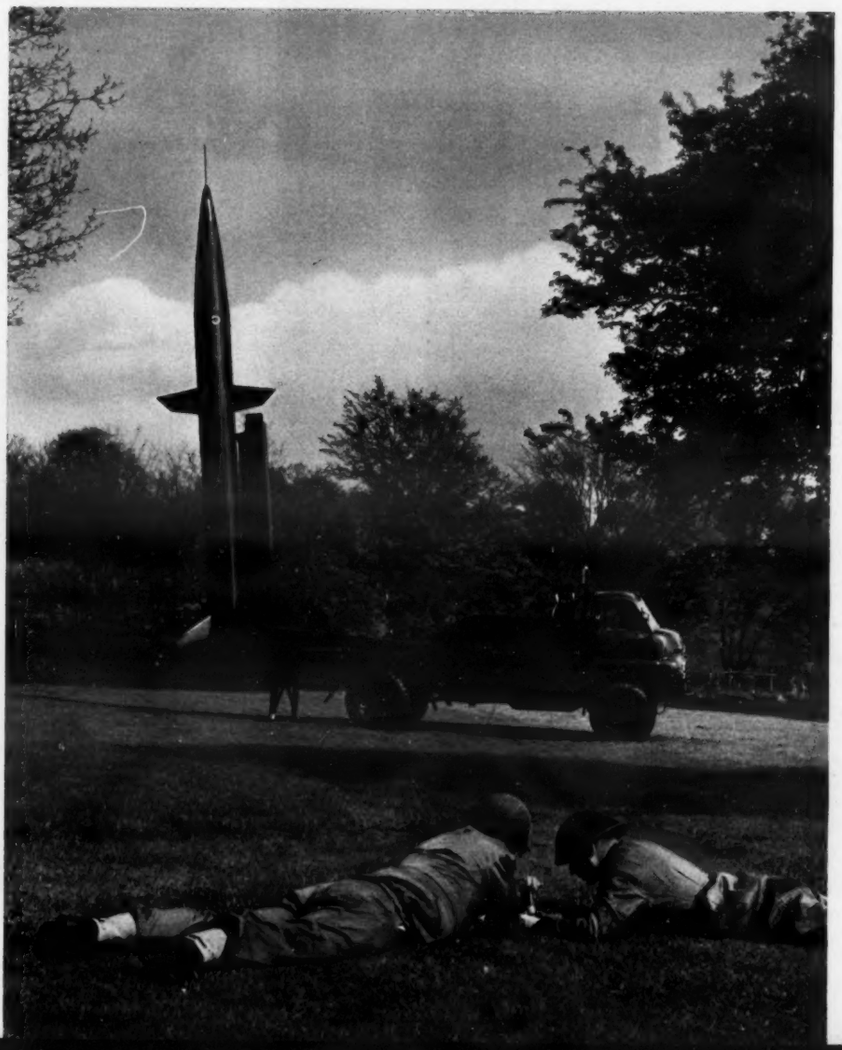
The Tartar Missile

Little detailed information has been released on the *Tartar* missile to date. The weapon represents an advance on the *Terrier 2* and the airframes of the two missiles are almost identical. The *Tartar* airframe, about 15 ft long and slightly over one foot in diameter, is shorter than the *Terrier* owing to the dual thrust boost/sustainer motor. The *Terrier* carries a booster motor which is detached after burnout, and this tandem installation accounts for the 27 ft overall length of the missile. The reduction in overall length of the *Tartar* makes it simpler to store and to handle in the confined space available aboard a destroyer.

The guidance of the *Tartar* is a semi-active radar homing system, and the missile carries a receiver dish aerial protected by a nose radome. In the shipboard installation, a Mk.73 director built by General Electric Ordnance Dept. controls a radar beam which locks-on and tracks the target. The director serves as the mount for the radar antenna of the AN/SPG-51 radar.

The *Tartar* is claimed to be effective against both low- and high-altitude targets, and with its supersonic speed and ten-mile range, it will become the primary anti-aircraft and anti-missile armament aboard destroyers and will replace the 5 in. guns in the secondary batteries aboard cruisers. ⟷

Blue Water Surface-to-Surface Missile



Personnel of the Royal Artillery demonstrated the new *Blue Water* tactical surface-to-surface missile for the first time at the 24th International Air Show in Paris. Developed by the British Aircraft Corporation (English Electric) in collaboration with the British War Office and Ministry of Aviation, the weapon, which is fitted with a nuclear warhead, meets the NATO requirements for a successor to the American Firestone SSM-A-17 *Corporal*. The *Blue Water* weapon system can be operated from all kinds of terrain and transported in aircraft of the *Argosy* class.

Thanks to its solid-propellant motor, the *Blue Water* is ready for operation at any time. Mounted on a three-ton truck with a combined launcher/transporter, it can be positioned and fired within ten minutes. A mobile computer provides the data which are fed into the inertial guidance system. Before the weapon reaches its target, the computer is taken to the next missile to provide fresh data for its guidance. Meanwhile, the first launcher returns to the artillery depot for reloading. Specialized personnel are not necessary for the operation of the *Blue Water* inertial guidance system, which is self-checking; the system can be operated by artillery personnel with a minimum of specialized training. Repairs are carried out by replacement of the faulty parts.

In the development of *Blue Water*, the British Aircraft Corporation was able to draw on the extensive experience of its member companies with the *Thunderbird Mk.1* and *Mk. 2* and the *Vigilant*. The following data have been released: length 25 ft; maximum diameter 2 ft; wing span 6 ft 9 in; tail span 6 ft 5 in.

◀ The *Blue Water* surface-to-surface missile in launch position. The range of this tactical missile is said to be over 100 miles.

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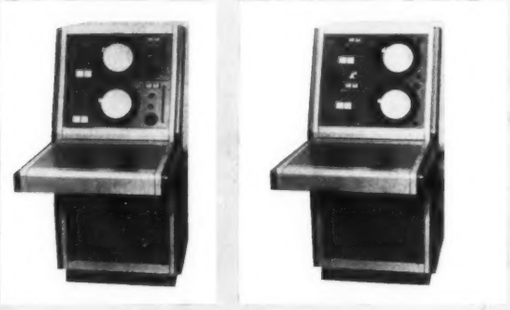

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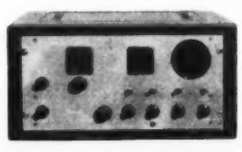

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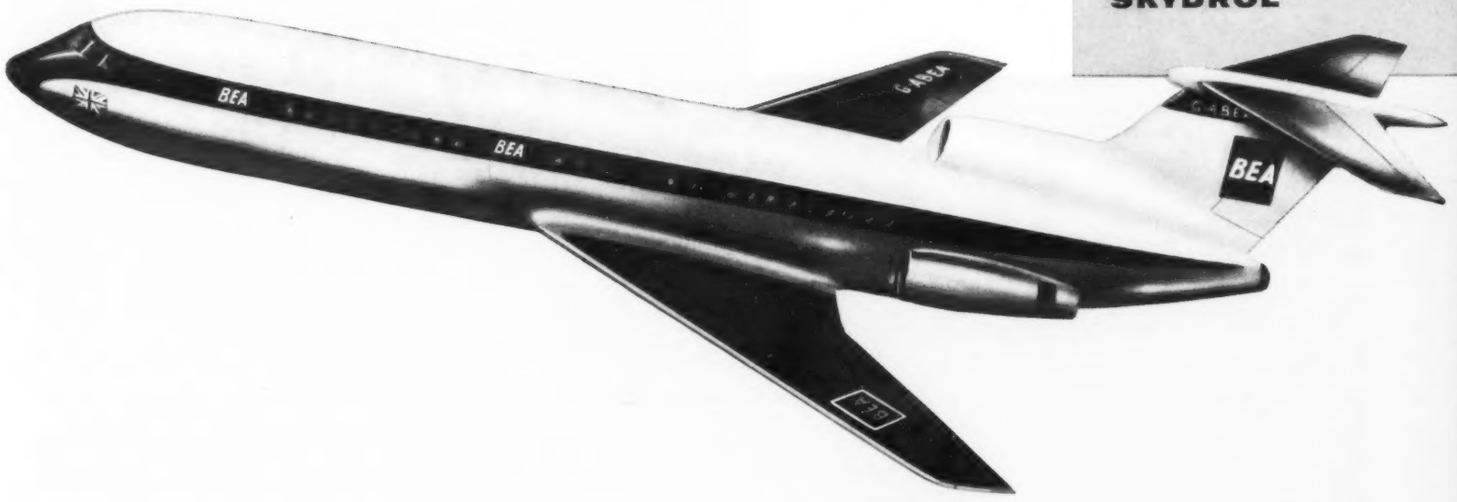

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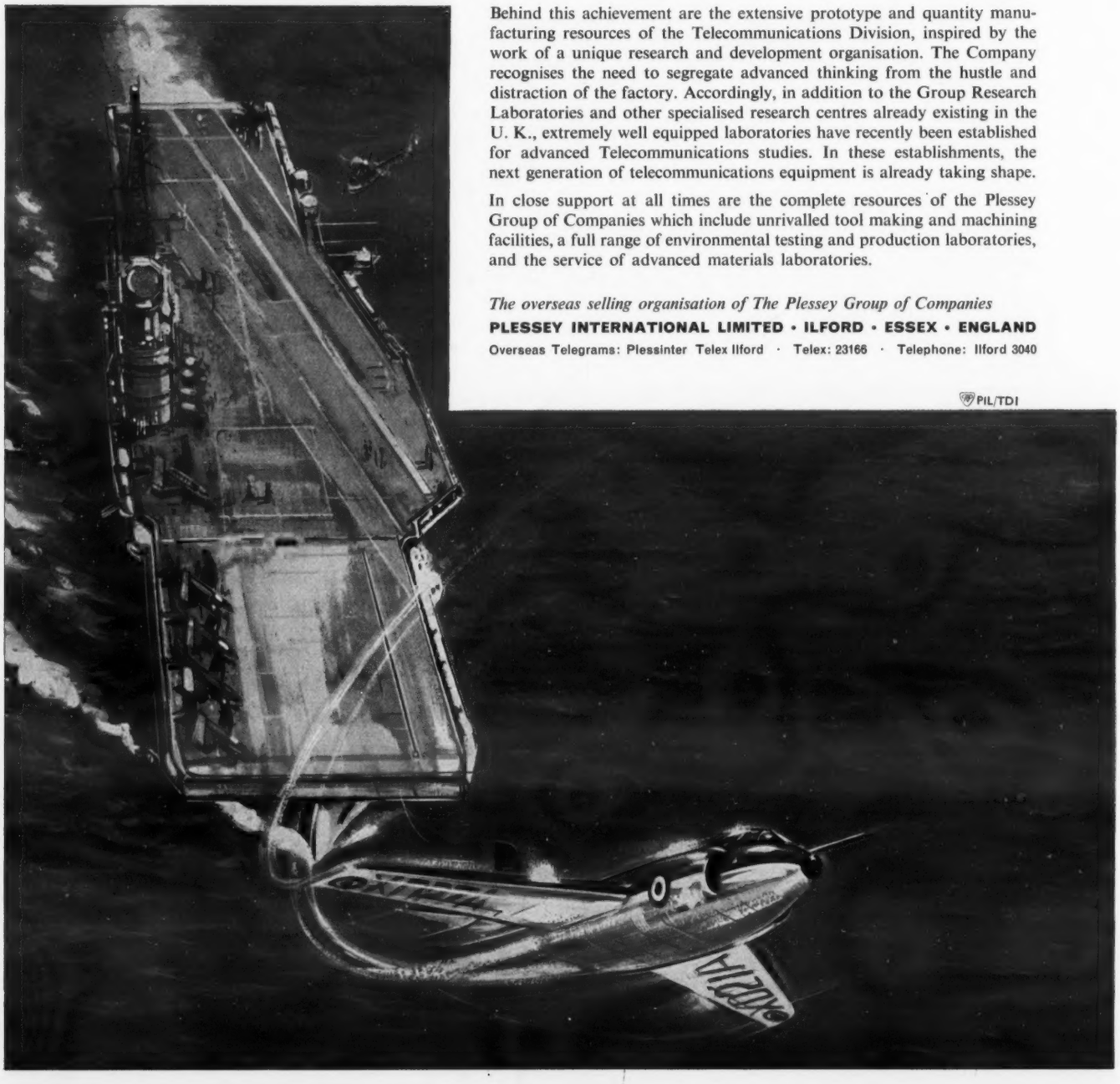

Behind this achievement are the extensive prototype and quantity manufacturing resources of the Telecommunications Division, inspired by the work of a unique research and development organisation. The Company recognises the need to segregate advanced thinking from the hustle and distraction of the factory. Accordingly, in addition to the Group Research Laboratories and other specialised research centres already existing in the U. K., extremely well equipped laboratories have recently been established for advanced Telecommunications studies. In these establishments, the next generation of telecommunications equipment is already taking shape.

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Solid Rocket Propellants

Development and Applications

By Dr. K. Klager, Aerojet-General Corporation, Sacramento, California

Dr. Karl Klager was born in Vienna in 1908. In 1939 he joined I.G. Farben and worked in their research laboratory at Ludwigshafen, where he was concerned with the development of propellants for rockets. Three years after the end of the war he emigrated to the U.S.A., where he was first employed in the Office of Naval Research in their Pasadena branch. In 1950 Dr. Klager worked for Aerojet-General Corporation on the development of various fuels. In 1955 he acquired American citizenship and took charge of a small Aerojet laboratory for the investigation of new solid propellants, out of which came polyurethane, the solid propellant which contributed materially to the realization of the U.S. Navy's Polaris *programme. This work laid the basis for the development and production of the solid propellants for the second stage of the* Minuteman *ICBM and for various rocket propulsion systems for use in space vehicles. Today, Dr. Klager is the Senior Division Manager, Solid Rocket Development, at Aerojet's Solid Rocket Plant in Sacramento, California.* *The Editors*

During the past decade, use of solid-propellant rockets has continually increased in almost all fields of military applications. The basic reasons are: (1) the continual improvement of the solid propellants, specifically the understanding of their ballistic and mechanical behaviour; and (2) the increase in design simplicity and the utilization of advanced materials in the inert components. These advances opened the door to development of solid-propellant rockets for the big boosters required in intercontinental ballistic missiles and space vehicles, thereby seriously competing with liquid-propellant rockets.

This paper deals with the advances made in solid propellants from the firecracker compositions of the early Chinese rockets used 700 years ago, to the current applications of rubbery, high-solids-content, solid propellant compositions of high ballistic performance. Since only gunpowder was available to the early rocket technologist, the history of rocket propulsion paralleled the history of gunpowder until about 1900, when liquid propellants were proposed or used in the now famous work of Ziolkowsky, Goddard and Oberth.

In 1939, Dr. von Kármán and his associates began the development of solid-propellant rockets for jet-assisted-take-off applications using composite propellants. Since that time, continuous emphasis has been placed on the improvement of solid-propellant compositions. Rapid progress in organic high-polymer chemistry during the 1930s and understanding of the thermodynamic processes in the combustion of solid propellants have been important factors in modern solid-propellant development, although many branches of science and technology have contributed significantly to this spectacular progress.

Definition and types of solid propellants

A solid propellant is a physical or chemical combination of an oxidizing and a reducing agent, which on ignition, evolves gas continuously without dependence on the atmosphere. There are two types of solid propellants:

1. The homogeneous, or double-base, propellant, consisting of a plasticized nitrocellulose-nitroglycerine mixture, where the oxidizing agent and the reducing agent are essentially in the same molecule.

2. The composite propellant, consisting of a heterogeneous mixture in which a combustible fuel is burned by a crystalline oxidizer. These propellants are either extruded or cast, depending on their viscosity.

The division between homogeneous and heterogeneous propellant is now disappearing, since solid oxidizers are being incorporated into the double-base propellants, and the fuel binder, backbone of the composite propellant, is being loaded with oxygen. Therefore, essentially we now speak only of composite solid propellants. Further, metallic additives are used as a part of the combustible fuel binder. These additives increase the caloric values of composite propellants exactly in the same manner as metals did in the composition of high-energy explosives.

Chemicals

Of the chemicals that are used for propellants, there are two main classes:

1. Oxidizers, which are 70 to 80 percent of the composition.

2. Fuels constituting 20 to 30 percent, part of which may be metal.

The oxidizer and the metal are held together by the fuel binder to form a solid mass. There has been very little latitude in the selection of a solid oxidizer, and the propellant manufacturer uses what the chemical industry offers. The principal oxidizers are shown below:

Oxidizers for Solid Propellants

	Available Wt % O_2	Density lb/in.^{3}	Heat of Formation Kcal/100 g	Mols of Gas per 100 g
$KClO_4$	46.0	0.090	82	0
KNO_3	39.5	0.076	118	0.495
NH_4ClO_4	34.0	0.070	59	2.55
NH_4NO_3	20.0	0.061	110	3.75
$LiClO_4$	60.0	0.087	86.5	0

Currently in use are the potassium and ammonium salts of perchloric and nitric acid. The choice of oxidizer depends on the required propellant performance.

In general, we can say, ammonium perchlorate is used for high-energy propellant compositions, and ammonium nitrate is used for low-energy propellant compositions, particularly for propellants used in gas generators.

Fuels, on the other hand, consist of binders and metal additives. Binders are available in a wide variety of synthetic-resin monomers, rubbers and waxes produced by the chemical industry. Further, cellulose derivatives such as nitrocellulose or cellulose acetate are also used in propellant fuel binders. In addition, low-cost commercially available monomeric materials can be used as structural units in the synthesis of new polymeric binders. These, then, lead to an infinite number of compositions to fit almost any set of physical and mechanical properties needed for a given application.

With the constant appearance of new chemicals and new low-molecular weight polymers, the versatility in formulating improved propellant fuels will continue to increase.

Requirements

If the propellant is to operate satisfactorily and the rocket is to fulfill its mission, certain requirements must be met by the propellant in the following terms:

1. Ballistic performance.
2. Mechanical properties.
3. Processability.
4. Cost.

In the following sections the importance of these requirements with regard to improvement of propellants will be explained. Obviously, improvements in any one of the propellant characteristics must not be accomplished at the expense of the others.

1. Ballistic Performance

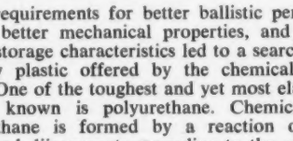
Specific impulse, or thrust per unit weight, is a very important factor in measuring the performance of any propulsion system. It is expressed as pounds of force in one second obtained from one pound of propellant. Obviously, the greater the specific impulse, the greater the range of the missile. The first composite propellants made from asphalt and potassium perchlorate had a specific impulse of 185 lbf-sec/lb. Double-base propellants had specific impulses in excess of 200 lbf-sec/lb. Today's propellants attain specific impulses of more than 240 lbf-sec/lb. By the use of thermodynamic calculations, we can calculate the specific impulse of a propellant if we know the amount of oxidizer, binder and metal additives in the formulation. These calculations serve as a guide in the preparation of propellants for evaluation. They show that near-stoichiometric compositions, in which all the chemical ingredients are converted into gases or high-boiling, low-molecular-weight liquids, give the highest specific impulses. This can be done only by loading the fuel with more and more inorganic oxidizer to completely burn every chemical element to its gaseous combustion product; however, the mechanical-property requirements of a propellant limit the amount of solid oxidizer and metal additives together that can be added.

Review of the Historical Developments of Composite Propellants

The first solid propellants, as stated earlier, consisted of a mixture of asphalt and potassium perchlorate. The overall performance was poor. The specific impulse, compared with today's requirements, was low – about 185 lbf-sec/lb – and the mechanical properties were substandard. In fact, during the higher operating temperatures, the propellant would begin to flow. Excessive smoke produced during the combustion of the propellant and objections to the lack of three-dimensional stability led to the development of vinyl polyester as a binder. This increased the three-dimensional stability, but the high curing temperature introduced stresses and strains in the propellant that prevented its use in casebonded grains. Excessive smoke during combustion was eliminated by the use of ammonium perchlorate instead of potassium perchlorate as oxidizer.

As further demands were made on the industry, especially for better utilization of space within a rocket for a higher mass ratio, the Jet Propulsion Laboratory developed polysulfide-based ammonium perchlorate propellant, which permitted bonding of the propellant to the case. This utilized the space better and protected the propellant from breaking during rapid acceleration. Other improved propellants were based on cellulose derivatives, or of a plastisol type using polyvinylchloride. These were the main propellants of the composite type until about 1953 to 1954. They had a maximum specific impulse of about 220 lbf-sec/lb.

The requirements for better ballistic performance, better mechanical properties, and improved storage characteristics led to a search of the new plastic offered by the chemical industry. One of the toughest and yet most elastic plastics known is polyurethane. Chemically, polyurethane is formed by a reaction of a polyol and diisocyanate according to the equation:



$$HO{-}A{-}OH + OCN{-}B{-}NCO \rightarrow \left[O{-}A{-}O{-}\overset{\overset{O}{\|}}{C}{-}NH{-}B{-}NH{-}\overset{\overset{O}{\|}}{C}\right]_x$$

As shown in this equation, a glycol is reacted with an isocyanate to produce a linear chain called a polyurethane. If a certain amount of glycol is replaced by a triol, a three-dimensional network is produced by the same polyurethane reaction. The mechanical properties of the polyurethane can be changed by varying the chain length of the glycol or the chain length of the isocyanate. Also, depending on the total amount of crosslinks or vulcanization, the mechanical properties can be changed from a very hard to a very elastic material — from a nylon-like material to a rubber. The most important characteristic is that the raw materials are liquids that can absorb large quantities of solids, such as oxidizers and metallic additives, to produce castable propellant compositions.

Since 1955, polyurethane propellants have found increasing use in all types of solid rocket motors — large and small. For instance, the first-stage booster of the *Scout* system is filled with polyurethane propellant. The chemistry of polyurethane is well understood and permits control of the mechanical properties; by controlling the vulcanization, or crosslink density, of the polyurethane propellant, the mechanical properties can be varied as desired. This process, simular to vulcanization of rubber, results in a product that has three-dimensional stability but is elastic enough, even when loaded with more than 80% solids, to withstand thermal stresses. This elasticity is apparent, although to a lesser degree, at temperatures as low as — 75 °F. The addition of aluminium raised the theoretical specific impulse to a total of 263 lbf-sec/lb at a chamber pressure of 1000 p. s. i.; currently, the highest theoretical specific impulse that has been attained in solid propellants.

Properties similar to those of polyurethane propellants are exhibited by copolymers made from butadiene and other polymerizable chemicals. These binders produce, in combination with aluminium and ammonium perchlorate, high-energy propellants characterized by good mechanical properties and good processing characteristics. Today's solid propellants are all made from chemicals commercially available in large quantities at modest prices and do not present material supply problems.

With too much oxidizer and metal, there is not enough binder to hold the particles together.

Another important performance factor is burning rate. Generally speaking, propellants containing ammonium nitrate oxidizers have low burning rates, those with ammonium perchlorate have medium burning rates, and those containing potassium perchlorate have high burning rates.

The size and distribution of the oxidizer particles and some additives also vary the burning rate; burning-rate catalysts may either speed up the burning or slow it down. Finally, since thrust is proportional to specific impulse and density, a higher-density propellant is desirable for a number of applications. Because the density of the oxidizer is essentially constant, propellant density is a function of fuel; hence, the highest-density fuel available should be used.

2. Mechanical Properties

The mechanical properties of a propellant are measures of its ability to maintain the integrity of the grain. Therefore, elastic and tensile properties and storage and aging characteristics are vital. Cracking of the propellant grain prior to or during flight of a rocket because of poor mechanical properties may cause a malfunction that would render a rocket useless.

Unfortunately, no single mechanical property stands out in the selection of a solid propellant, such as specific impulse or burning rate, in the ballistic requirements. Generally, the elastic modulus of a propellant must be low enough to prevent cold flow during storage but high enough to prevent gross deformation under operating conditions such as ignition pressurization, drag on the propellant by a high-velocity stream of combustion gases, and acceleration of the rocket. On the other hand, the propellant must have a high enough elongation to withstand strains caused by thermal shrinkage and dimensional changes during cure. Because the propellant is much weaker than the metal parts and mechanical properties of the propellant are more dependent on time and temperature than those of the metal, the difference in thermal expansion coefficient between the metal and the propellant results in considerable strain that must be absorbed by the propellant. This is why mechanical properties are so important in solid rockets. The most commonly measured mechanical properties are tensile strength and elongation; however, another significant property that is measured is ability to resist strain for a long period of time.

3. Processability

Propellant must be processed to produce an economical, reliable and reproducible product. In the past, these requirements have been met, for both homogeneous and composite propellants, by the well-known batch-mix process. Great quantities of propellant have been made by this process. However, for the large quantities of propellant needed for future development and the stringent reproducibility and reliability requirements for the new rockets, a better mixing procedure was sought. The continuous-mix system for composite propellants is believed to be a better process. It is much safer than the batch-mix process because only about 25 lb of propellant are mixed at any one time. It is more economical than the batch-mix system, and one continuous mixer will produce about as much as five 2,200-lb batch mixers.

Some of the characteristics that determine producibility of composite propellants are pot life, castability, curing time, curing temperature, curing exotherm, and shrinkage. All of these significantly influence the final product. For instance, the total shrinkage of a propellant during cure, both thermal and chemical, introduces a strain in the propellant. The higher the curing temperature, the higher the thermal strain and the greater the demand for better mechanical properties to maintain the integrity of the propellant grain. The absence of exothermic reaction during cure permits the processing of large-diameter grains; no runaway reaction can take place that will lead to catastrophic autoignition while the propellant is curing.

4. Cost

The costs of solid propellants are due to raw material and processing. The raw material currently used in polyurethane propellants are about 36 cents per lb. Processing, which includes cast and cure operations but not fixed equipment or tooling, will bring the total cost of the propellant to about 85 cents per lb. If a continuous mix process is used to produce at least 30,000 lb of propellant a month, a labor-saving of 25% can be realized. Future propellants using so-called "exotic" fuels will have higher raw material costs. Justification for their increased costs will be the improved performance.

Future Developments

What does the future hold and how are we to attain future goals? We have two ways of planning ahead: first, by the use of thermodynamic calculations that will give us information on where improvements can be expected; second, by assigning a price to the theoretical thermodynamic compositions to find out if we can afford such a system for a proposed mission.

Today, composite propellants are composed essentially of three main components: the oxidizer, the metallic fuel, and the fuel binder. Replacement of one or all three of these chemicals by materials having a much higher energy content will lead to propellants of improved performance on the basis of thermodynamic calculations. These calculations indicate that we can, by the use of more energetic oxidizers, light metals, and new fuel binders containing fluorine that have not yet been synthesized, produce propellants with specific impulses 20 to 25 percent higher than the existing theoretical specific impulse available today. Some of these new chemicals do not yet exist, and we have no assurance of when they will be synthesized, when they will become available, and whether or not they will result in the propellant mechanical properties required to fulfill our needs. The use of these ingredients may present some serious problems. These materials must be synthesized and their chemistry understood. If they react with other materials in a propellant, they must be protected either by a metal or a plastic coating, and some of these materials are extremely reactive. Finally, these materials must be used in a propellant formulation and the propellant must be evaluated.

Economic calculations will help select only those propellants that show both technical improvements and cost reductions for the intended use. These calculations show that today's propellants are hard to beat, and future solid composite propellants of high energy may have limited applications because of costs. Solid propellants will have new competition either from liquid or hybrid (combination liquid and solid) propellants in various applications. These too may have economic advantages over the future ultra-high energy solid propellants. The competition is healthy. Who is going to win the prize will depend on the performance and price of the propellant for the intended mission. Only accomplishment of the mission should be the criterion for future applications of the possible propellant systems. ←→

Space Research
An Investment in the Future

United Aircraft and Republic Explore Ahead

At the inauguration of their Research and Engineering Center at Sunnyvale near San Francisco on April 13th 1961, the United Technology Corporation (UTC) unveiled a full-scale model of the conical segmented solid propellant rocket engine, which is to be test fired in a few months' time. Technical data: thrust 250,000 lb; duration of combustion 60 seconds; nett weight 75,000 lb.

During the last decade, the development of the American aviation industry has been characterized by the headway of the guided missile. Whilst many old established aircraft constructors were content with building some guided missiles as a sideline, others built huge works, engaged staffs of highly qualified scientists, and spared no effort to set up in this new and highly promising business. One well-known concern, which can look back on a great tradition in aircraft construction, has even gone over entirely to rocket weapons.

And change in the structure of the industry is again beginning to manifest itself. This change has been set off by the hectic progress in space technology, a field whose significance it is as yet impossible to measure. At first, space research was almost exclusively the province of a few government research institutes and of some universities, but it did not take long for far-seeing industrialists to realize that, unless they exercised private initiative in the field of research and development, they would have little chance of being considered for later production orders.

The picture shows the propellant mixer station located at UTC's new Development Center, an hour or so by car from San Francisco. The mixer (left) can deal with 3,000 lb of solid propellant at a time, under remote observation from a control room (right) by means of closed circuit television.

The traditional resources of the aviation industry are, however, far from adequate for space research. There is admittedly some relationship, between carrier rockets and long-range weapons—currently available boosters are, in fact, no more than surface-to-surface guided missiles with overall modifications—but the development and equipping of space vehicles calls for a fundamentally new technology. Branches of science with which the aviation industry has hitherto been unconcerned or, at the most, only marginally concerned, for example cryogenics, vacuum technology and astronomy, are now becoming of the utmost importance. Thus an industry which is on the one hand in danger of having to lay up part of its facilities owing to the continual recession in aircraft, on the other finds itself confronted with the necessity of new investment on an appreciable scale. Again, the future should justify those who are prepared to build on a generous scale. It is already certain that space, apart from its military significance, is not merely an academic subject, but also offers entire industries a new field of activity and the incentive of highly-promising markets.

It is therefore hardly surprising to find that one American aircraft concern after another is setting up research facilities, the scale and appearance of which take a little while to get accustomed to. In April, two such concerns put facilities of this kind into operation within the space of hardly three weeks. On the West Coast, United Technology Corporation opened research, testing and production facilities for high-thrust carrier rockets, and in Farmingdale, near New York, Republic Aviation Corporation inaugurated seven scientific laboratories for space vehicle development.

Segmented Carrier Rockets by United Technology

Late in 1958, United Aircraft Corporation founded a new subsidiary, United Research Corporation, with the object of developing propulsion systems for guided missiles and space vehicles in close cooperation with the Stanford Research Institute. General Donald L. Putt, who had retired a few months earlier as Deputy Chief of Staff, Development, USAF, was appointed President of United Research, and amongst the eminent scientific advisers engaged was Dr. Isidor J. Rabi, Professor at Columbia University and Nobel Prizewinner for physics. A few months later the corporation changed its style to United Technology Corporation. Today, this go-ahead concern has some 550 employees, over a third of whom are university graduates.

UTC's test stand for solid propellant rockets, installed at Morgan Hill Calif., designed for 2,000,000 lb thrust. Later in the year, this facility will be used to fire rocket engines of 250,000 and 500,000 lb thrust.

Exterior of UTC's new curing oven. With a diameter and depth of over 20 ft and 40 ft respectively, this oven can take rocket engine combustion chambers in the 1,100,000 lb thrust class. A 50 ton mobile hoist is used to lift the oven's lid and to lower and raise the engine casing segments. This crane, which is 57 ft high × 50 ft wide and said to be the largest on rubber tyres in existence, can itself transport the rocket engine segments over the prepared roads of the test area at a maximum speed of 100 ft per minute and without the need for loading on to another vehicle.

In November, 1959, United, using their own resources, started work on segmented solid propellant rocket engines; these are engines whose combustion chambers consist not of one piece but of several segments secured together. The advantages of this type of construction are easy to see. The manufacture of small units is considerably cheaper than the building of one-piece mammoth boosters; the dimensions and weight of the segments can be easily kept within the limits necessary for transportation by road or rail, namely diameter 10 ft, length 10 ft, maximum weight 115,000 lbs; should a fault in manufacture show up before launch, it is sufficient to exchange the offending segment; the box construction principle is flexible and allows a wide variety of combinations, as rockets of every desired thrust class can be built up of relatively few and, moreover, basically similar units; if instead of joining the segments to form a single combustion chamber, thrust nozzles are interposed between them so as to provide several genuine stages, very favourable mass ratios can be achieved with the same basic units.

The arguments advanced by the engineers of United in support of the conical shape of the combustion chamber are no less illuminating. If one increases the port area through which the gases flow, the length of the combustion chamber can almost be unlimited, moreover one can set the duration of combustion more precisely and can more easily eliminate instabilities in combustion. The erosion effect of flames is largely avoided and, as it is possible to keep wall thickness of the propulsive charges in successive segments constant, simple build-up is sufficient to increase the total thrust of a rocket. Lastly, the conical shape gives the rocket more stability in flight and reduces aerodynamic heating.

After the preliminary theoretical work had yielded a basic concept, in June 1960 NASA gave an order for further investigations to prove the serviceability of the principle, by means of three small experimental rockets. The first firings took place last December and turned out to the complete satisfaction of all concerned. This was also the first opportunity for testing the joints, which hold together the individual segments. These light-weight mechanical joints, developed by United in close cooperation with Pratt & Whitney, are a clevis type, similar to a tongue and groove with shear pins.

On the strength of the results of these preliminary experiments, NASA awarded a contract for developing and testing a solid propellant engine of 250,000 lb thrust. The first firings are planned to take place this summer, and in autumn an engine of double strength will be tested. United intends to develop a family of rocket engines, the most powerful of which is to have a thrust of 3 million lb. By using clusters of these rockets as first stages of large launch vehicles, thrusts of some 7 million lb would later be feasible. Provided the necessary financial support is forthcoming from the Administration, a 2 million lb thrust booster could, according to United, be available by 1964 at a fifth of the price of comparable liquid rockets. United estimates the costs of development of a Nova class booster (15 to 20 million lb thrust) at $150 to $200 million.

Whilst directing its main effort to segmented rockets, United is also working on storable liquid rockets and hybrid propulsion systems, in which solid fuel is combined with a liquid oxygen carrier. This is a field in which development is only just commencing and experimental installations of all kinds are indispensable for realizing such ambitious projects.

United Technology Corporation has not remained idle. On the San Francisco peninsula it has built a Research and Engineering Center which includes mechanical work shops and a series of laboratories. The research laboratories are devoted primarily to basic research in the fields of physical chemistry, propellant chemisty, physical properties of propellants and materials, and general physics. The development laboratories are equipped for propellant synthesis and evaluation, including synthesizing solid and liquid propellants, drying and grinding granular materials, propellant processing, testing small rocket engines, and studying explosive phenomena.

An hour away by car, in the Californian hill country, is the rocket production and testing plant, which includes installations for propellant mixing, for handling and curing the charges, test stands for liquid rockets, and a group of seven test stands for solid propellant rockets! Six of these are designed for thrusts of about 250,000 lb, whilst the seventh can take mammoth boosters in the 2 million lb class. There is a centrally located blockhouse for the remote control of firing. Our pictures give an idea of the scale of these installations, with which United has certainly prepared well for the future, as there is nothing that the American space effort needs more urgently than high thrust carrier rockets.

Republic Develops Space Vehicles

Among the concerns whose confidence in manned aircraft never wavers is Republic Aviation Corporation. Its latest creation is the all-weather *Thunderchief* F-105 single-seat combat aircraft, which is at present in series

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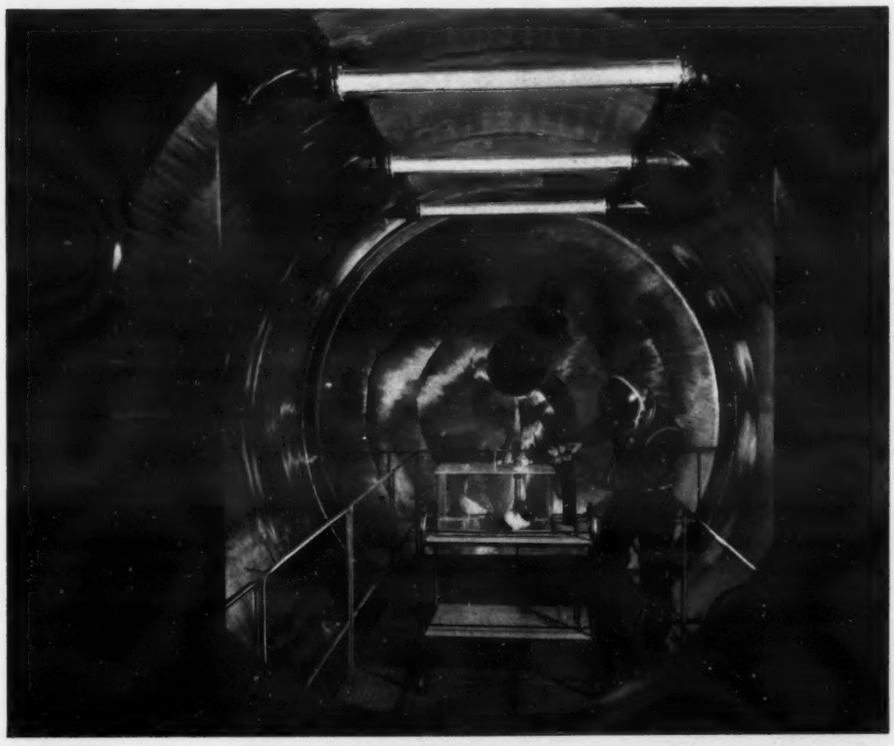
Republic Aviation Corporation has installed an air and space research laboratory, the Paul Moore Research and Development Center, at Farmingdale near New York, at a cost of $ 14 million. The center was officially inaugurated on April 29th, and includes seven laboratories and several wind tunnels. One of the laboratories is for investigating the behaviour of materials and components under the effects of high intensity, and especially radioactive, radiation. Robots (as s own in photo) are used by Republic's scientists to carry out complicated manipulations as part of remotely-controlled radiation experiments.



Space inside the laboratory. In this 30 ft long vacuum chamber, conditions corresponding to those encountered at altitudes of 150 m can be simulated. This c amber, equipped with slow motion cameras, and a variety of recorders and measuring instruments of all types, is intended first and foremost for space medicine research, but can also be used for testing space vehicles and their parts. This installation is part of Republic's Space Environment and Live Sciences Laboratory at Farmingdale.

Mach 20 speeds are obtained in this 100,000 p.s.i combustion driven shock tunnel belonging to Republic's Re-entry Simulation Laboratory. At the end of a 120 ft long tube is a 24 in test section inside a vacuum chamber.

▼

production and which is gradually replacing the F-100 in Tactical Air Command. Moreover, as is well known, work has been going on for years at Farmingdale on various STOL and VTOL concepts, partly in conjunction with Fokker, Netherlands, a third of whose share capital is owned by Republic.

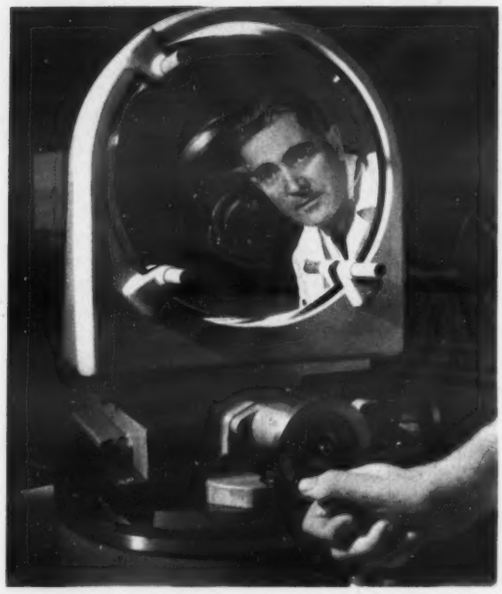
All the same, the Board decided in July 1958 to extend considerably the corporation's field of activity. If it was formerly the practice to test the serviceability of a concept by means of one or more prototypes, the complicated weapons systems of today now rule this out on grounds of expense. Instead, all fundamental questions must be solved in a theoretical way, and particularly by experimental research in the laboratory and at the test rig. The idea of the prototype therefore completely loses its significance, and what is produced is in fact a pre-series model, which is merely subjected to a few final corrections and modifications.

The efforts which industry must make today if it is to survive are evident from a study published by Republic, from which it emerges that in 1953 this concern had nine competitors in the field of development contracts whereas it now has 37, not counting institutions attached to universities and other non-profit making organisations.

These and similar considerations may well have been the main ones behind the decision taken by the Board of Republic to make the creation of a Research Center the central theme of its four-year programme. This Center, consisting of seven laboratories and several wind tunnels and built at a cost of $14 million, has now been substantially completed—except for a shock tunnel which is still under construction—and was officially inaugurated on April 29th, 1961. It was named the Paul Moore Research and Development Center, after one of the founders of the Enterprise.

The Space Environment and Life Sciences Laboratory

Here, doctors, psychologists, botanists, zoologists and engineers jointly study the influence on living organisms of the environmental conditions encountered in space. What physiological and psychological effects do absolute silence, loneliness (or communal life in an extremely confined space), and weightlessness have on a human being? How can one best protect the space traveller from excessive accelerations, dangerous radiation, extreme temperatures, poison gases, and meteorites? How can a space crew be supplied with food, drinking water and air to breathe even on long journeys? This gives an idea of the questions which are at the forefront of current research in this laboratory. Some scientists are investigating the question as to whether and how vegetables and other plants or could be grown on the moon; a "garden" of this type would be an essential element in a "moon colony" for the maintenance of the natural "oxygen cycle. The main



An electronic capacitor, less than one millionth of an inch thick, under examination in Republic's Guidance and Control Systems Laboratory. The giant dome in the foreground is part of a special machine for depositing thin films of metallic or semi-conducting materials on glass or ceramic strips. Microminiaturized components of this kind are for the logic circuits of computers intended for use in guided missiles or space vehicles.

In the same laboratory, work is in progress on the development of optical systems for gyro-stabilised star-tracking. One of the advanced instruments used for testing such systems is an over 15 ft long auto-collimator, which provides a beam of parallel light (visible and infrared portions of the spectrum) with a diameter of 16 in. Illustrated here is an 12 inch optical flat mirror, which is a key element of the collimator.

installation of this laboratory is a 30-ft long test chamber which can be evacuated to an air pressure corresponding to that found at an altitude of some 150 miles above the earth.

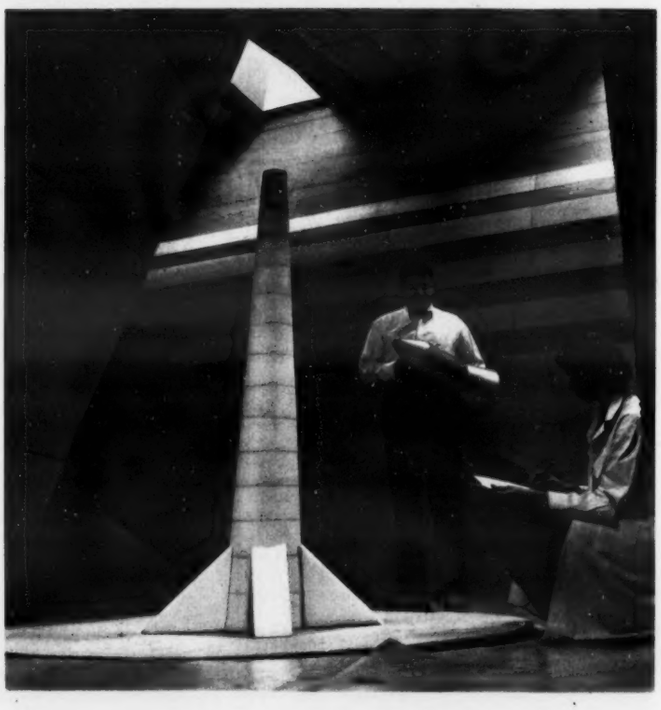
The Re-entry Simulation Laboratory

For the study of conditions encountered at re-entry, small models of space vehicles are here subjected to flows of 20 times sonic speed in a shock tunnel. A 50ft ballistic range allows the simulation of free flight conditions, a hydrogen gun providing the necessary "environmental conditions". In order to study the effects of meteorite attacks on various materials, plastic models are fired at speeds of nearly 26,000 mph at the materials being evaluated.

The Guidance and Control Systems Laboratory

Advanced optics, solid state physics, and cryogenics are but three examples of branches of science which play a significant part in the development of navigation systems for space vehicles. The most immediate objectives include the development of a "moon tracker" (autopilot for moon probes), and of micro-miniaturized data memories, binary-decimal converters, and other components of space-borne computing devices. Work is going on at high pressure on further development of the LASER techniques.

The Electronics Laboratory at Republic's Center includes a chamber for radar reflection testing. The chamber walls are fully anechoic. In this particular test, being carried out on a metallized re-entry vehicle model, the radar cross section is determined by means of radar waves bounced off the model in various positions, to determine the angles of maximum and minimum reflection.



The Fluid Systems Laboratory

Republic has already been working for eight years on hydraulic systems. Amongst the outstanding results of this research is a hydraulic liquid which works perfectly at temperatures of over 1,000°F. At present, the various applications of advanced systems for the thrust vector control of rockets, the regulation of nuclear reactors, and the adjustment of wings of variable sweepback are under study.

Control Systems of space vehicles must work with equal reliability at extremely low or extremely high temperatures. Five experimental chambers are available for testing work liquids, and seals, hydraulic fittings, pneumatic components, material and complete equipment. In these chambers temperatures ranging from minus 320°F. to plus 1900°F can be obtained at pressures up to 5800psi.

The Electronics Laboratory

New stabilizers for S/VTOL aircraft and all types of electronic airborne instruments, particularly systems for the transmission of information between space vehicles and earth, are on the programme of this laboratory. Special importance is attached to the configuration of the antenna, and to test the radiation characteristics of antennas a completely radiation-free test chamber has been installed, in which the electromagnetic waves multiply in practically the same way as in space, that is to say they are not reflected by the containing walls. Another experimental chamber, the screen room, is completely electrically shielded against the the outer world and is for the purpose of measuring the noise behaviour of electronic equipment.

Nuclear Radiation Laboratory

The pride of scientists in this laboratory are two test chambers in which materials and components can be subjected to high-intensity radiation; with the aid of robots even complicated jobs can be carried out in the contaminated area. These investigations serve on the one hand for the development of radiation-resistant materials and on the other for the improvement of various measurement processes.

Materials Development Laboratory

Here, traditional and exotic materials are subjected to "all known tortures", including durability and fatigue tests at both high and low temperatures, under the influence of hard radiation, under high pressure, shock and impact tests, and so on. With the aid of electron microscopes, high pressure autoclaves, spectrophotometers and other equally expensive instruments, Republic's scientists try to wrest the "innermost secrets" from metals, plastics and ceramic materials.

Wind Tunnels

As regards installations for aerodynamic experimentation, a transonic tunnel is available for static experiments and flutter tests at lower speed ranges. A second tunnel is for experiments in the Mach 1.5 to 4 range, duration according to Mach number, stagnation pressure 40 seconds to three minutes. A hypersonic tunnel for testing models up to 1-ft diameter in blasts corresponding to Mach 14 is under construction; about one million ceramic "pebbles" will be used to preheat the air, these being heated to nearly 3,000°F prior to the test.

With this Research Center at its disposal, Republic Aviation can face the future with confidence. Whether it is a question of aircraft, guided missiles, or space vehicles, the Farmingdale scientists have the tools at their disposal.

Semi-finished Materials in Light Metal for Aircraft Construction

By Prof. Dr.-Ing. P. Brenner, Bonn

It was after the first world war that light metal construction, based on the prototypes created by Junkers and Dornier, began to make headway at the expense of the wooden and mixed constructions which had, until then, been in general use. Aviation as we know it today would be unthinkable without light metals, especially heat-treatable aluminium alloys.

Airships had already been built earlier of aluminium. After Schwarz's abortive attempt, Count Zeppelin decided, shortly before the turn of the century, to use aluminium as the material for his first airship. He and his colleagues were also the first to take up *Duralumin*, and from 1914 onwards all Zeppelin airships were built in this material. *Duralumin*, discovered in 1908 by Alfred Wilm in Berlin, had more than double the tensile strength of the unalloyed aluminium in use until that time. When, towards the end of World War I, Professor Junkers constructed the first aeroplane in light metal, he was already in a position to turn to good account the experience gained in the construction of airships with *Duralumin*.

Since then, development has continued at a tremendous pace, on the one hand in the field of alloys and the semi-finished materials produced therefrom, and on the other in construction methods as regards both configuration and the actual process of manufacturing. The state of the art today is the fruit of methodical cooperation between aircraft constructors, production engineers, and manufacturers of semi-finished materials.

Development of Alloys

a) Static resistance characteristics

The development of aluminium alloys for aircraft construction is characterized by a constant increase in tensile strength and in yield point. The first success was to raise the tensile strength and yield point of the original *Duralumin* by 15 to 20 percent by means of alloy techniques. Materials of this type, known in the USA as 24 S (2024) and in Germany as Fl. W. 3125, were introduced several years before the war, and still represent the most widely used material for aircraft (AICMA designation AI. P13).

Further progress in this direction came with the AlZnMg alloys, which were orginally developed in Germany under the designation Fl.W. 3425, and were already in use on a large scale during the war in aircraft struts and other highly stressed parts. Further post-war developments in the USA led to the 75 S (7075) and 78 S (7178) alloys, the first of which has a minimum yield point of 66,000 psi and a tensile strength of 76,000 psi and the second 76,000 psi and 86,000 psi respectively. Whereas 75 S (AICMA designation AI-P42) can now be considered standard material for military and civil aircraft, the use of 78 S has so far been confined to a few American models. The characteristics of some of the main aluminium alloys used in aircraft construction can be seen from the table.

Sheets and strips are also produced from most of these alloys. Thin sheets (up to 3 mm) are best used plated; the pure aluminium or AlZn layer, which is deposited on to both sides during manufacture of the semi-finished materials, imparts a high resistance to corrosion as a result of the electro-chemical protective effect, even at those points where there is a break in the plating, e. g. at the cut edge.

b) Fatigue strength

Unfortunately there is no gain in fatigue strength to match the improvements achieved in static resistance. This is particularly true of complicated components with uneven stress distribution, since the notch sensitivity of these materials generally increases with higher tensile and yield strength. The effects of rivet, screw, and spot-welded joints are very unfavourable from this point of view. So as to be able to also use highly resistant materials with advantage in cases where fatigue stresses are present, the constructor must minimise notch effects and design the configuration of his aircraft components in such a way as to distribute the stresses as homogeneously as possible; this is a problem of fundamental significance in modern aircraft construction.

The methods of construction evolved have frequently necessitated the production of semi-finished materials in special shapes. Some examples are briefly described below.

Semi-finished materials in special shapes

Besides normal semi-finished materials, such as sheets, strips, tubes, profiles etc., various special semi-finished materials have been developed to meet the requirements of aircraft constructors. These are characteristic applications of aluminium alloys, and in most cases these special materials cannot be made of other non-ferrous metals or of steel.

a) Sheets and strips of variable thickness

As early as the beginning of the war, the German semi-finished materials industry supplied the aircraft industry with so-called tapered strips, which were used on a large scale for spar flanges and skins. Today, taper-rolled plates represent a

The Main Aluminium Alloys Used in Aircraft Construction

Category	Designation			Approximate chemical composition					Properties (minimum values)			Remarks
	AICMA	USA	LN[1]	Cu	Mg	Zn	Mn	Cr	$\sigma_{0.2}$	σ_B	δ	
Extruded Sections												
AlCuMg2	Al-P13(T3)	2024-T4	W.3125.6	4.5	1.5	—	0.5	—	36	48	10	Also for sheets and strips
AlZnMgCu1,5	Al-P42(T6)	7075-T6	3.4364.7	1.5	2.5	5.5	0.3	0.2	50	55	7	plated and unplated
AlZnMgCu2	—	7178-T6	—	2.0	2.7	7.0	0.3	0.2	55	60	5	plated and unplated
Drop Forgings and Machine Forgings												
AlMgSi1	Al-P21(T6)	6061-T6	W.3355.7	—	0,8	—	0,8	0,3	25	30	7	Drop forgings
AlCu4SiMnMg	Al-P12(T6)	2014-T6	3.1254.7	3.4	0,5	—	0,8	—	39	46	7	Drop forgings
							+0.8	Si	39	46	10	Machine forgings
AlZnMgCu0,5	Al-P43(T6)	7079-T6	W.3425.7	0.6	3.3	4.3	0.2	—	43	51	8	Drop forgings
									43	51	9	Machine forgings

1) Federal German standard

Fig. 6: Four-high stand for the cold rolling of strips up to 1,300 mm wide at the Bonn works of Vereinigte Leichtmetallwerke.

standard semi-manufactured material for the aircraft industry. They simplify configuration and manufacture of wings and wing components, since the necessity for strength reducing joints at the abutments no longer arises, a fact which is of particular importance in the case of fatigue stresses.

b) Extruded profiles

The extrusion press production makes it possible to a large extent to match the configuration and the dimensions of profiles to the specific construction task, and the variety of profiles delivered to aircraft factories is extraordinarily large (see *fig. 1*). Ribbed sheets can also be produced in this way, by first extruding an internally ribbed tube, then cutting it along its length, and finally opening and flattening it. In this way, continuous ribbed sheets up to 900 mm wide can be made, and the transition from sheet to rib formed in such a way as to eliminate notch effects (such as occur, for instance, in the case of rivet joints).

c) Thick plates for integral construction

The easy machineability of aluminium alloys permits intricately shaped components, such as the upper and lower sides of wing skins, to be milled from the solid. This production process, known as integral construction, starts from thick plates, from which the outer skin, which thins out towards the wing tip, together with the tapering longitudinal and lateral ribs, are milled. In this way, points at which stresses arise can be easily reinforced.

As compared with conventional methods, integral construction has the following advantages:

– The component can be formed as to achieve as homogeneous as possible a distribution of stresses;

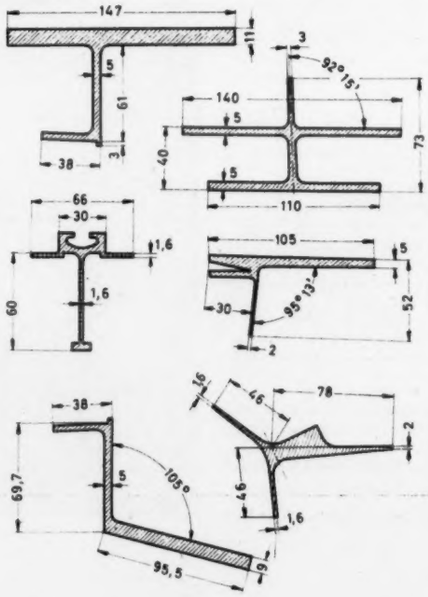
– A large number of joints, such as seams, bolts, spot welds etc., are eliminated, which considerably reduces weight and increases resistance, and at the same time appreciably cuts labour costs.

On the other hand, severe demands are made on the quality of the plates, as more than 80% of the metal is machined off in the whole process. Faults in the material, such as cavities, cracks and oxide impurities, which show up in machining, render the whole component unusable, thus increasing costs.

To avoid warping during milling, the plates must be free of inherent stresses. The most effective way to avoid the quenching stresses arising from heat treatment has been shown to be stretching by 2 to 3 percent. For this purpose plate stretchers with a strength of several thousand tons are required but, up to now, stretchers of this kind have not been available outside Great Britain and the USA.

For the *Chemmill* chemical milling process, which is more suitable for smooth components, thinner plates are used.

Fig. 1: Cross-sections of some of the extruded sections used in European aircraft types. Measurements in millimetres.



d) Honeycomb materials

The tendency of thin-skinned components to ridge was formerly met by stiffeners. The development of light and resistant supporting materials (bonded honeycomb made of aluminium foil) made it possible not only to increase ridge resistance, but also to achieve an aerodynamically smooth outerskin, such as had not so far been feasible in metal parts. In the last few years, sandwich components, comprising a honeycomb centre bonded between two thin plates, have been used more and more for tail assemblies, control surfaces, cabin flooring, etc. In the *Trident* and the Breguet 1100 and 1001 (*Taon*) aircraft, sandwich construction has also been adopted extensively for stress-bearing parts of the airframe. Aluminium honeycombs are generally produced by bonding aluminium foils, laid one on top of the other in parallel strips and staggered from layer to layer. Sections of the resulting layer blocks are then expanded to form honeycombs with hexagonal cells.*

In another process developed by Vereinigte Leichtmetall-Werke, Bonn (VLW), separators are injected during the casting process and form a system of canals running parallel and staggered at each level, and they are retained during the rolling process. The rolled plates are then expanded in a similar manner to the blocks (see *fig. 2*). The honeycomb cells produced in this way are not as small as in the foil bonding process, but, on the other hand, have the advantage of being "one piece" honeycombs without joints. Moreover for these *Monalcell* honeycombs, as opposed to the *Alucell* honeycombs, heat-treatable aluminium alloys can be used, resulting in considerably more resistant cell walls.

The same principle can also be applied to other single material components, such as ribbed sheets. For this purpose, only a single layer of separation elements is used and, after cutting longitudinally, the strips are squared off with a special machine tool. Sheet thickness, rib thickness, distance between ribs, and height of ribs can be altered by varying the arrangement of the separation elements in casting, and by differentiating the rolling time *(fig. 3)*. These components, branded *Ripal*, can also be produced with longitudinally variable sheet thickness and rib thickness, similarly to tapered sheets and strips.

Heat resistant aluminium alloys

Although aluminium alloys possess excellent strength characteristics at low temperatures, their heat resistance is limited. The fact that aluminium alloys are nevertheless successfully employed in such thermally stressed components as pistons, cylinder heads and compressor valves, must be attributed to the good heat conducting properties of aluminium, as a result of which maximum temperatures can be raised, and the heat distributed and led off to cooler points, thus reducing maximum thermal loading.

In the case of supersonic aircraft, where heating takes place by air friction, there is no thermal dissipation to match the heating—unless, of

* *Alucell*, produced by Vereinigte Leichtmetall-Werke, Bonn.

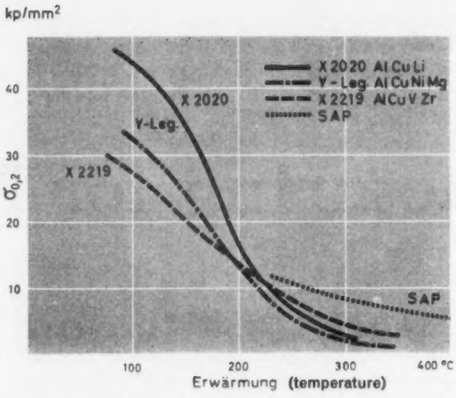


Fig. 4: Yield points of some heat-resistant aluminium alloys as a function of temperature. In the higher temperature range SAP sinter material is markedly superior to all other alloys.

course, a special cooling system is installed, which is hardly practicable. Where the heating periods are short, as in the case of rockets, the temperature of the material can be kept down by heat-insulating layers made of ceramic, plastic, or similar materials.

The tensile and yield strength of the usual heat-treatable aluminium alloys drop appreciably at relative low temperatures, especially when both heat and stresses are operating simultaneously, so that these materials are practically ruled out for speeds over Mach 2. Of the aluminium alloys with increased heat resistance developed in the last few years, special mention should be made of alloy X 2020 (with about 4½ percent copper and 1 percent lithium) and of alloy X 2219 (with about 6½ percent copper and small additions of vanadium and zircon).

Creep tests at constant loading at increased temperatures have shown that, up to about 200°C, the thermal behaviour of X 2020 is more favourable than the Y alloy used up till now for heat stressed parts; the same is true of X 2219 at temperatures between 200°C and 300°C.

For higher temperatures (250°C–450°C), *S.A.P.* sintered metal is considerably superior to the heat-treatable aluminium alloys. Moreover, far from being at an end, development in this field can be expected in the near future to lead to light metal materials suitable for use up to Mach 3.

Fig. 4 shows the 0.2% yield strength of the four materials so far mentioned, at temperatures up to 400°C.

Production of semi-finished materials

The production of semi-finished materials in light metal, for use in building aircraft, demands not only special, and generally extremely costly, installations, but also a large force of reliable, experienced, and adaptable workpeople. In order to conform to the exacting demands of aircraft constructors, it is essential to keep a close watch on manufacturing conditions and to provide for meticulous quality control of the semi-finished materials. The ever-increasing severity of aircraft constructors' requirements makes comprehensive research and development indispensable.

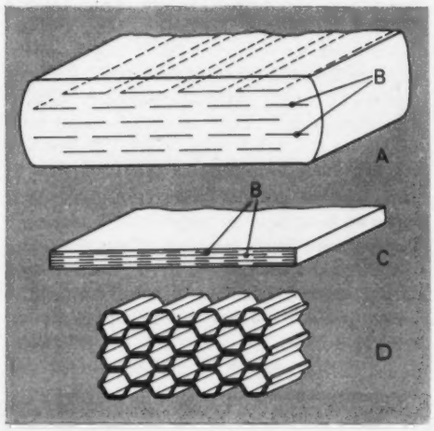


Fig. 2: Vereinigte Leichtmetallwerke, of Bonn, has invented a process for manufacturing *Monalcell* integral honeycomb. During the extrusion of rolled blocks (A), parallel rows of separation elements (B) are injected to interleave the structure. The separations are maintained during rolling. After it has been rolled flat (C), the block is stretched to form a notch-free honeycomb (D). This process can also be used for heat-treatable aluminium alloys.

In contrast to the USA, where the aviation authorities finance the installation of heavy forging and extrusion presses, plate stretchers, and the like, the European semi-finished materials industry is obliged to manage with normal plant. This is because the special plant necessary to produce semi-finished materials for aviation cannot normally be adequately employed, and its acquisition is therefore not justifiable from the purely commercial point of view. This fact often gives rise to difficult problems, both for the semi-finished material producer himself and for the aircraft constructor. VLW has been foremost amongst the European manufacturers of semi-finished materials in making a speciality of producing semi-finished materials for aircraft and in contributing to the development of such materials, especially by the plating process, the extrusion forming process and the AlZnMg alloys. Before the end of the War, this concern had plants in Bonn, Hanover-Linden and Hanover-Laatzen.

When the Hanover-Laatzen plant was dismantled after the war and various major equipment, such as a 15,000-ton forging press and a 12,000-ton extrusion press, had to be surrendered as reparations to the USA, the remaining plants at Bonn and Hanover-Linden were extended and developed in line with modern needs (see fig. 5/6).

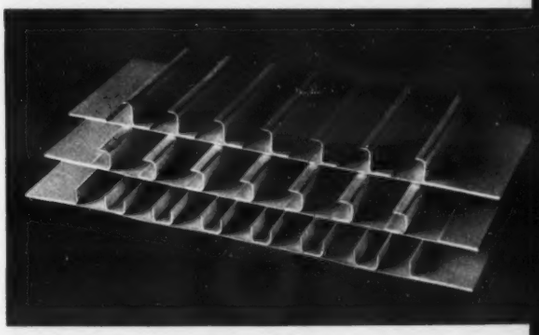


Fig. 3: Integral ribbed sheets, prepared from extruded ribbed tubes.

The Bonn and Hanover plants are equipped with extrusion presses up to 5,000 tons, and the Bonn plant is to receive a 7,200-ton oil hydraulic press about the end of this year. By that time the block foundries, the rolling mill installations, and the heat treatment installations at both plants will be considerably expanded, with a view to the special demands of aircraft construction. The Hanover plant also produces forged and stamped parts, for which purpose a 7,400-ton hydraulic forging press is available, besides smaller machines.

In the period after the war, when Germany was forbidden to build aircraft, VLW was delivering semi-finished materials to foreign standard specifications to the French, Swedish, Netherlands and Italian aviation industries, as well as to the American repair facility in Germany. With this experience behind them, VLW was in a position to deliver the necessary semi-finished materials without delay, as soon as West Germany resumed the production of aircraft. ↔

Fig. 5: Hot rolling mill at the Hanover-Linden plant of Vereinigte Leichtmetallwerke (VLW).

Manufacturing for Mach 3

This edge preparation machine can handle sheet steel up to 16 feet wide. The cutter shears the edge of the steel and can turn up a lip as small as 12 thousandths of an inch, in preparation for butt welding.

When North American Aviation, as prime contractor for the B-70 *Valkyrie*, commenced preparations for the production of this aircraft, a vast number of new manufacturing problems had to be solved.

Whilst many high-performance military aircraft in service today are capable of speeds above Mach 2, the actual duration of such high-speed flight is relatively short, and aluminium alloy structures are capable of withstanding the kinetic heating produced. The concept of the B-70, on the other hand, demands the ability to cruise for intercontinental distances at speeds of Mach 3, or approximately 2,000 m.p.h., at heights above 36,000 ft.

At a cruising speed of Mach 3 in the stratosphere, the skin will be subjected to temperatures approaching 300 °C, and on deceleration to subsonic speed, to a rapid cooling to around −40 °C. To withstand the loads and heating stresses caused by flight in these conditions, steel was chosen as the structural material.

The introduction of new materials, and the demand for welding in place of rivets for jointing, presented so many problems that North American established a Manufacturing Development Program to conduct research into new techniques. A total of 28 research projects were included in the programme which, in the words of a North American spokesman, "will provide the manufacturing knowhow for the next generation of radically new aircraft."

The research into new production methods has resulted in the development of several new machines, all capable of working to extremely close tolerances. In the machining processes, considerable use is made of tape control, and a number of government-owned numerically-controlled machines were directed to North American at the commencement of the B-70 programme. Typical of the high precision equipment installed in the Los Angeles plant is a steel-cutting spar mill with a bed 114 ft long, which will machine long steel stock to a tolerance of 0.0005 in.

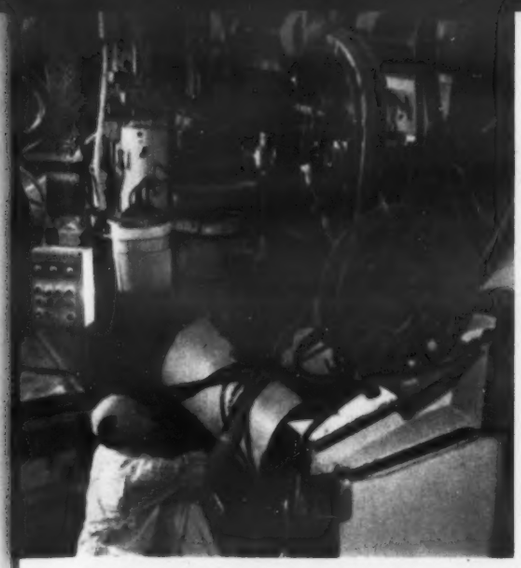
Much of the external structure of the B-70 is fabricated from stainless steel brazed honeycomb sandwich with facing sheets as thin as 0.0006 in. This stainless steel sheet is hardly thicker than foil, and special machines had to be developed to handle the thin but unwieldy sheet and to prevent the formation of wrinkles. An extra thousandth of an inch thickness in this skin would, however, add over a ton to the weight of the aircraft.

Welding techniques

As the basic design of the B-70 calls for machine fusion butt welding to join the stainless steel panels, and these parts are too large to rotate a pass under a fixed welding torch, new methods had to be developed. North American developed means of holding the work stationary whilst automatically moving the welding torch along a precise path. The equipment now in use is capable of welding sheets up to 16 ft in width and of any length. Sheets of constant thickness or those tapering from one side to the other can be joined. The welding head is also fitted with a seam tracking device, so that sheets of varying configurations can be welded.

This automatic welding machine is electronically controlled, to eliminate the possibilities of human error. The control ensures a constant and dependable arc-welding power supply, and accurate welding-speed and positioning control. It also fulfils part of the quality control procedure, by enabling welding parameters to be checked before the work is commenced. Test specimens are welded together at an established feed rate,

A sheet of rolled stainless steel only 0.02 in. thick being delivered to North American. This sheet was manufactured by United States Steel and measures 260 × 308 inches. It will be used for the production of steel honeycomb panels.



This skin mill has been converted for the electrolytic grinding of honeycomb core or small steel solids to high accuracy tolerances.

and then X-rayed. The X-ray photographs are then studied by the production laboratory for cracks and examination of the weld build-up. The welding parameters used for the specimen are then entered on a certification sheet and are used afterwards for all similar jobs.

A boom-type welding machine with a reach of 12 ft and capable of making circumferential and longitudinal welds in a 20 in. diameter envelope has also been developed. Closed circuit TV is provided as an integral part of the machine, to enable the welding operator to monitor the weld area continuously.

It was also found during the manufacturing development phase that an X-ray source could be mounted to move along the same guide rail which carries the welding head, so as to provide continuous exposure of strip film. This enables a complete record to be maintained of each weld as it is made and maintains a continuous quality control.

The enormous amount of welding required in the construction of the B-70 and the demand for a continuous quality control are illustrated by the fact that there are more than 19,000 ft of fuel-tight fusion welding alone in the structure. The majority of this welding is carried out by machines.

For joining internal structural members, two types of spot welding are used. These are the conventional resistance spot and the Heliarc spot. Resistance spot welding with opposing electrodes is used in sections with ample clearance, while Heliarc spot welding, which requires no opposing electrode, is used in restricted or blind areas.

Honeycomb brazing

The brazed honeycomb sandwich panelling used for the main exposed surface structure of the B-70 is made from PH 15-7 Mo stainless steel. As part of the brazing process it is heat treated to a minimum yield strength of 200,000 p.s.i. and an ultimate tensile strength range of 225,000 to 260,000 p.s.i.

Owing to the differing panel shapes which are required, three basic brazing methods are employed. These are the furnaceless (electric blanket), the salt bath, and the platen (or die quench) methods. The last of these has proved to be the most rapid and economical and is best suited for flat panels. The parts to be brazed are encased in a retort and placed in a pre-heated furnace, where they are brought to a temperature of 1,625°F. The retort is then transferred to a press and clamped between the faces of a water-cooled die, resulting in very rapid cooling. The metallurgical characteristics of the panel are also improved by this method.

In all three brazing processes, a temperature of approximately 1,625°F is required to melt the brazing alloy, and it is essential that all sandwich parts are cooled after brazing at constant, controlled temperatures. All the preparation of the materials, the honeycomb brazing alloy and the outer sandwich skin, is carried out in special temperature-controlled dust-free rooms by handlers wearing gloves, as even a fingerprint will prevent proper brazing.

To maintain strength requirements in sandwich construction, perfect brazing must be accomplished in every panel. The use of X-rays for internal inspection proved both expensive and lengthy. To overcome this problem, North American has now developed an ultra-sonic inspection system. Each finished panel is immersed in a tank filled with pure water and a scanning head traverses over it, transmitting sound waves through the panel. The result is a visible record on photo-sensitized paper, which indicates every part of the honeycomb core that has brazed to the skin, and reveals any areas where the bonding has been missed or is faulty.

Tubing developments

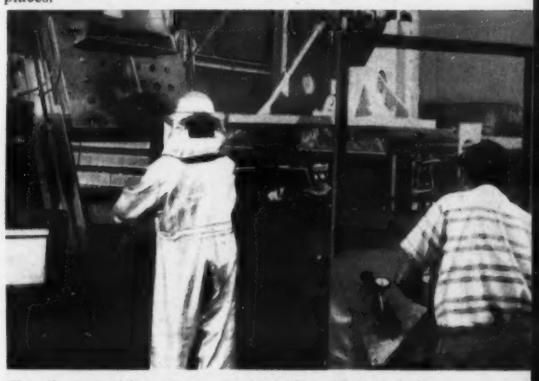
The demand for light, thin-wall tubing capable of carrying the 4,000 p.s.i. hydraulic pressures used in the B-70, and also of withstanding temperatures up to 540°F, presented a number of problems. Eventually, high-strength AM-350 stainless steel was selected and a programme was planned to determine the feasibility of forming, flaring and swaging the tubing.

To provide tube joints of adequate strength to meet B-70 requirements, induction brazing techniques were employed. In this process a sleeve is slipped over one tube, which is then butt-jointed to another. The sleeve is then placed over the joint and an induction coil clamped over the sleeve. High frequency electric current passed through the coil melts the brazing material lining the sleeve, and a leak-proof, high strength coupling is made. The heat is applied so rapidly, for a duration of seven to ten seconds in fact, that the heat treatment properties of the tubing are unaffected. In addition to the strength factor, the use of brazed couplings in place of the conventional threaded fittings, has saved over 1,000 lb in structural weight.

*

Whatever the future may be for the B-70 itself, the research and development which have gone into new manufacturing techniques will have far-reaching effects. Discussions on the shape of the future supersonic transport invariably turn on the question of designing for Mach 2.2 in light alloy or for Mach 3 in steel. The arguments directed against the Mach 3 solution are invariably based on the material handling and production problems which will be encountered in the construction of steel airframe structures. Many of these problems have been recognized and overcome in the B-70 programme, and the existence of the civil supersonic transport has thus been brought appreciably nearer. ◆◆

The induction brazing technique for tubing joints is demonstrated on a simulated fuselage. The brazing can be carried out at distances of up to 100 ft from the generator, and enables joints to be made in inaccessible places.



The die quenching process in operation. The work is being inserted in the press, where it will be rapidly cooled between the faces of the water-cooled die.

Tool makers in the Columbus plant check an assembly tool which prevents the steel section from warping during the welding process.

The ultra-sonic testing tank for honeycomb panels. The sonic head transmits a sound wave pattern through the part submerged in the tank, and a record is produced on sensitized paper which reveals the quality of the internal brazing.

Manufacture of Solid Rocket Cases at General Electric

By R. H. Wettach, General Electric Company, Flight Propulsion Division, Evendale, Ohio.

General Electric has been active in rocketry for the past 16 years. Among the Company's contributions have been the X405 first stage *Vanguard* engine, the plug nozzle engine concept and roll-formed solid-fuel rocket cases. The Evendale plant was selected for the location of the solid rocket case facility for several reasons. The tools and skills required for precision manufacture of jet engines were readily adaptable to solid rocket case production. Also, the availability of a 42-inch Cincinnati Hydrospin machine on which the early development of roll-formed cases was performed was advantageous.

The roll-forming process affords excellent material utilization and permits the procurement of a cylinder forging at considerably reduced cost. It has the further technical advantage of eliminating the longitudinal weld which is inherently the weakest point of a rolled and welded case.

For maximum case quality, the case does not leave the plant once the various components are welded together. With hardware as sensitive as solid rocket cases, a mere dent or scratch incurred while shipping the case from one location to the other could cause rejection or considerably reduced reliability.

Roll forming

Four components, a machined forward head, a machined aft adapter, and two cylindrical roll-formed sections, make up a typical large diameter rocket case. After the cylindrical preform is obtained from the forging vendor, it is accurately machined to a predetermined wall thickness and length.

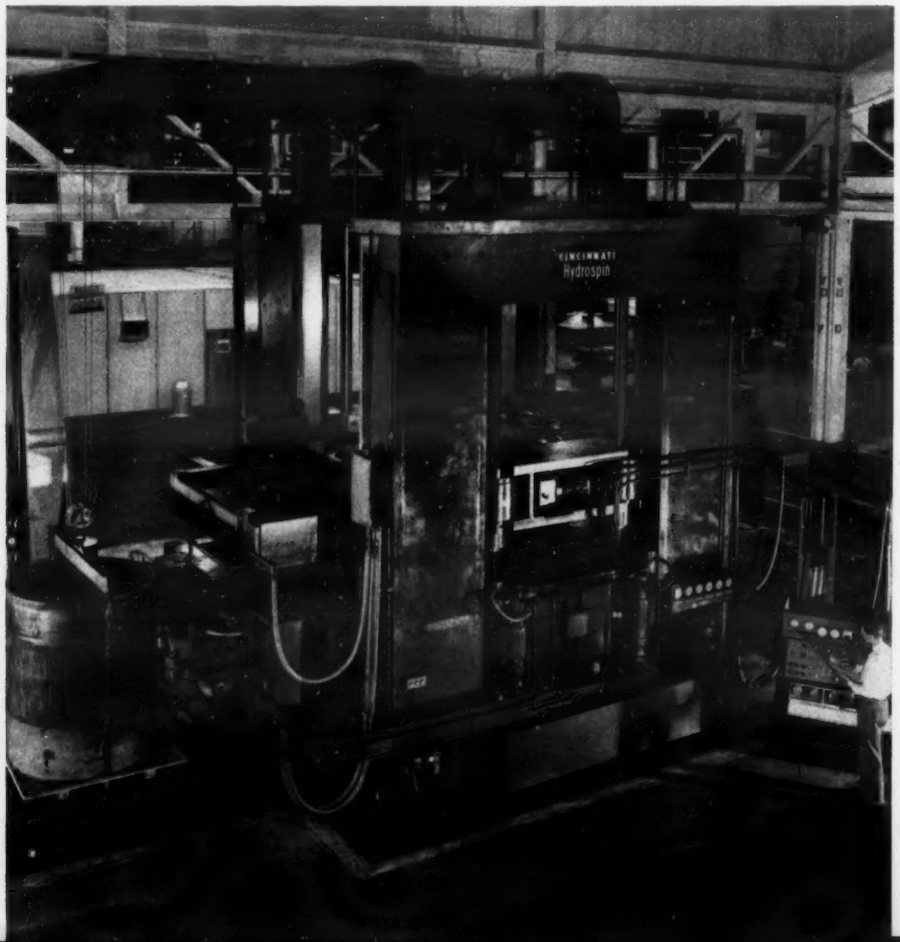
A Cincinnati 75 × 100 inch Hydrospin Machine was purchased for cost reduction programs on jet engine components, as well as rocket cases. The working rolls have a travel of 104 inches and a horizontal travel of 42 inches. This movement will permit manufacture of a cylinder 78 inches in diameter and 100 inches long, as well as any curved or conical shape that would fit into this envelope. The tail stock will move 104 inches vertically, but also can be moved sideways to permit the forming of cylinders 200 to 300 inches long. The control system is located remotely from the machine, and numerical control can readily be included in the system for automatic operation.

All machine movements are actuated through ball screws. The roller housings containing the working rollers will swing in a 100° vertical arc. Cross slide movements have a stroke of 42 inches, and will position the working rolls to the center of the machine with a force of 250,000 pounds. Main slide movement has a stroke of 125 inches with a force of 225,000 pounds at operating pressures of 2,500 p.s.i. The tail stock, which can be used to strip parts from the mandrel, has a force of 100,000 pounds. A three-ton crane is situated above the machine structure.

The headstock is driven by a 350 h.p. motor. The faceplate has a speed range from 8 to 141 r.p.m. at constant torque and from 141 to 283 r.p.m. at constant horsepower. The feed range (vector feed rate) is infinitely variable from 1/4 to 20 inches per minute.

The cylindrical preforms are placed on a steel mandrel secured to the faceplate of the machine. The working rolls are positioned taking into consideration the various characteristics of the machine, the roller diameter, and the material being formed. The working rolls move into the material and then downward toward the headstock, forcing the material upward between the mandrel and the rolls. This process is called backward extruding, and permits close control of the dimensions of the final cylinder. As the length of the cylinder is increased, the wall thickness is decreased, with a predetermined percentage of reduction in the material.

This fully automatic machine for the production of combustion chamber casings comes from Cincinnati. The engineer at the control console to the right gives an idea of the vast dimensions of the machine. With a base measuring 19 ft square, it has an overall height of 38 ft, being sunk to a depth of 17 ft under the floor of the hall, and weighs 500,000 lb.



Welding

After the finished roll-formed cylinders are trimmed, they are ready for welding to the aft adapter and forward head.

The welding of cases is an exacting process that requires close control. Rugged, accurate positioning and turning equipment that will operate smoothly, and at precise speeds, is also necessary. To satisfy these requirements, a special Lewis welding machine was designed. The machine consists of four basic units. These include a horizontal lathe, a precision Sciaky welding head with electronic controls, and single-purpose tooling. *Figure 2* shows the machine set up with typical tooling.

The lathe and welding head can handle a range of parts varying from 3 to 30 feet in length, and 12 to 72 inches in diameter. The diameter capacity can be increased to 100 inches if necessary. Rotary speed of the machine is infinitely variable from .02 to .3 r.p.m. for a surface speed on a 33 inch diameter of 3 to 40 inches per minute, and the drive system is accurate to 1 per cent.

Heat treatment

After the case is completely welded together, its strength requirements are obtained by heat treating. Housed in its own four-story building is the country's largest, most modern heat treat system, designed specifically for precise treatment of large, high-strength, thin-walled rocket cases (*Fig. 3*). The high (1,030 kW) power rating of the furnace makes it possible to raise an

The Lewis precision welding machine for the construction of combustion chambers. The electro welding head was developed by Sciaky Brothers Inc., of Chicago (*Fig. 2*).

8,000-pound load of steel from 1,000° to 1,500 °F in one hour.

The system consists of a high-temperature gantry furnace, two pit furnaces for combination preheat, tempering, and stress relief, one salt quench tank, one still-air quench station, one combination water quench and rinse station, and supporting atmosphere and control equipment. Additional pits are included to provide oil quench and other facilities as needed.

The gantry furnace is a refractory lined and insulated cylindrical steel structure mounted on a power-driven carriage which revolves, at floor level, around the top of a circular pit. Work to be heat treated is transferred between the gantry and pit furnaces by a gas-tight chain-hoist system which provides hoisting speeds ranging from 5 to 60 f.p.m.

Two cylindrical pit furnaces may be used for a combination of preheat, tempering and stress relief operations requiring temperatures between 400° and 1,400 °F. They are refractory lined and insulated steel structures with removable top covers. The furnaces can accept loads measuring 10 feet in diameter by 30 feet long, and each is equipped with a 21,000 c.f.m. recirculation fan to assure optimum circulation.

The salt quench and water quench/rinse stations are also cylindrical tanks heated by four gas-fired heaters. The salt quench is designed for continuous operation at 300° to 1000 °F with circulation of the molten salt accomplished by three solution agitators. The water quench/rinse tank has an operating range up to 180 °F, with water circulation provided by a 250 g.p.m. pump. The tank is heated with radiant gas burners.

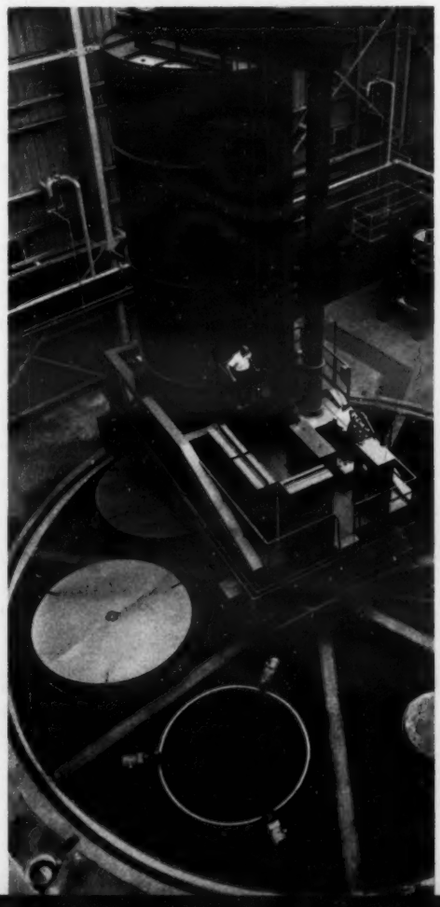
Thread milling

After the case is heat treated, it is sent to the thread milling operation. The primary purpose here is to generate the tapered buttress screw thread on both the case and the closure. This thread is used to join the two parts in their final assembly.

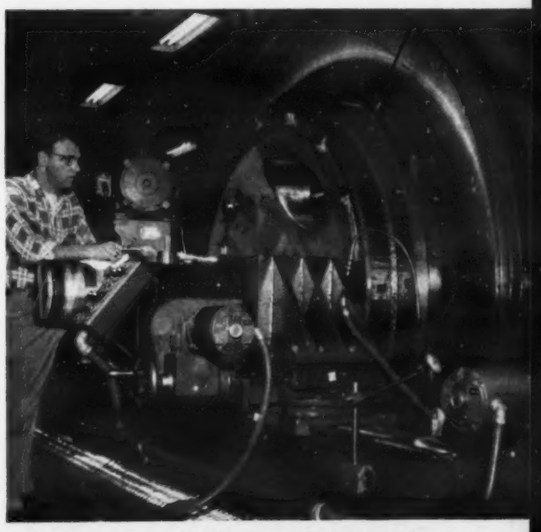
All the machining operations on the welded case are done after heat treating. Since some of the cases are tempered at a temperature as low as 600 °F, it is possible for the hardness of the modified 4340 material to be in the neighborhood of Rockwell C 54–55.

To accomplish the accurate dimensional control required in the finished case, the special milling machine must be extremely rigid. For example, the machine shown in *Fig. 4* is bedded into 54 cubic yards of concrete. The drive unit weighs more than 35 tons, and the tailstock or rear unit weighs 20 tons. The main drive spindle is 95 inches in diameter and weighs 5 tons. This spindle can accomodate cases with diameters up to 72 inches. The machine is unique in that the spindle is driven from the outside diameter, with the part actually located inside the spindle. The spindle itself is mounted on 24 needle-bearing rollers.

A master slide permits any angular pattern that may be required on the case joint. The machine is designed so that operators may perform operations at both ends of the case simultaneously. Feed range of the machine varies from .200 to 1 inch per revolution with a speed variation of one revolution in $3^1/_2$ hours up to 4 r.p.m. The tooling used in conjunction with the machine is also extremely heavy and solid, permitting the reduction of machine vibration.



This installation for the heat treatment of high-tensile, thin-walled combustion chambers requires a four-storey building for its accommodation. Maximum dimensions of the sections to be treated are 10 ft in diameter and 30 ft in length (extension to 40 ft is possible). The furnace can be set to any temperature up to 2,000 °F with an accuracy of ± 10 °F. Installed electrical power 1,030 kW (*Fig. 3*).



Combustion chambers with diameters of up to 72 inches can be precision-threaded on this special machine. The sections are fitted into a 10,000 lb jig with an external diameter of 95 inches (*Fig. 4*).

Quality control

General Electric has the capability to produce hardware. But steps must certainly be taken to assure that the product meets necessarily stringent quality standards.

"Total Quality Control" is employed to meet these objectives. This means control that begins with consideration of the drawings and specifications, and continues through the procurement of raw materials and processing of parts, up to and including the testing and inspection of the cases. It implies not only control of dimensions, but also control of processes.

To accomplish this, G.E. maintains a complete quality control organization, which includes reliability engineering, process control engineering, inspection and testing, physical and chemical laboratories and modern computers.

The company has complete dimension equipment, including large optical tooling case measuring stands and precision tooling and rotating tables. In addition, there are complete X-ray facilities, ultrasonic facilities and one of the largest magnetic particle inspection installations in the United States (*Fig. 5.*).

It is on facilitie ssuch as these, and especially people well trained in their utilization, that the company's reputation in this business is built.

What's in the Air?

NASA's test stand I-B at the Edwards Rocket Site, California, will handle full-scale testing of the Rocketdyne 1.5 million-lb-thrust F-1 engine early this summer. The stand has been designed for testing two F-1 class engines but can be enlarged a group of four. Height is over 250 feet. The two spherical tanks contain 75,000 U.S. gals. of liquid oxygen and 60,000 U.S. gals. of fuel. Note man arrowed to give comparative size of the facility.

AIR TRANSPORTATION

The International Civil Aviation Organization 1960 report quotes a preliminary figure of $50 million overall profit on total revenues of $5,500 million for scheduled airlines in 1960. International traffic was up 20.8 percent and domestic services 8.9 percent. Highest gains were shown by European and Latin American carriers at 25 and 21 percent respectively, but increases in the Far East, Oceania and the Middle East were substantial (16—20 percent). U.S. international and domestic operations showed a gain of only 7 percent with the U.S. share dropping for the first time below 60 percent of the world's total.

Total capacity was up 16.5 percent giving an estimated 55.5 percent average load factor for combined international and domestic world scheduled services. A load factor of 53.6 percent for domestic services was the lowest in history. On international services the figure was 58.4 percent. Largest regional increase in passenger traffic was shown on the North Atlantic, up by 395,000 to a total 1,761,000 (1,920,000 including charter and special flights, an increase of 25 percent). North Atlantic passenger traffic has increased from 1,020,000 in 1957. Sea passengers now comprise less than one-third of the total North Atlantic traffic.

Fatal accidents totalled 32 in 1960 with 850 passengers killed, compared with 570 in 1959. ICAO emphasizes that the increase rate was slight (from 0.95 deaths per 100 million passenger-miles to 1.25), and is not large enough to conclude that there has been a change in the long downward trend period. ICAO feels that 1959 was a "good" accident year whereas 1960 was exceptionally bad. Increased use of jet aircraft by world carriers was not the cause of the higher accident toll.

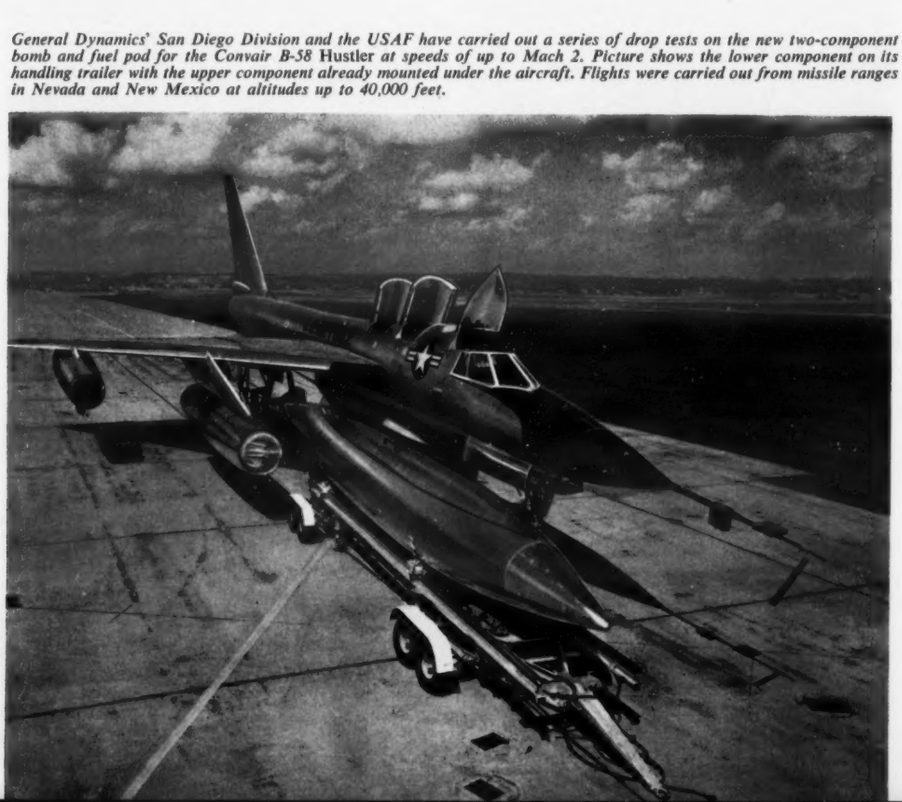
Venezolana Internacional de Aviacion S.A. (VIASA) of Caracas has become an active member of IATA bringing current membership to 89. VIASA is the eleventh Latin American flag carrier to join IATA.

The South African Government last month refused to increase KLM Royal Dutch Airlines' quota of 100 passengers a week at Johannesburg and the Dutch carrier will postpone introduction of Douglas DC-8s on the Johannesburg run (originally scheduled for August 7th). KLM maintains that DC-8s cannot be operated economically on a twice-weekly frequency with the current quota but further talks are being held. The South African action appears to be part of a Government squeeze on foreign operators who are not in a position to retaliate against the Springbok partnership in Europe or Africa. SAS is in a similar position to KLM, although it does have pick-up rights in Nairobi, but Convair 990 delivery delays will probably cause postponement of jet service to South Africa until early 1962. Similar South Africa action against Sabena appears likely but airlines with something to offer the Springbok partnership have had quotas increased. Rome is important to Springbok members and Alitalia's quota has been increased from 100 to 140 a week. French carrier UAT has had an increase from 60 to 88 a week.

Varig's purchase of REAL's subsidiary Aerovias Brasil appears to be the first step towards establishment of a single Brazilian international carrier. Brazilian President Janio Quadros has said that the financial outflow for aircraft and components, fuel costs and operating expenses could be cut by consolidating the interest of the Brazilian international carriers. Next major step in this direction will undoubtedly involve Brazil's third international carrier, Panair do Brasil. Varig is taking over Aerovias Brasil's international routes to Miami, Los Angeles, Chicago, San Francisco and to Tokyo via Peru, Columbia and Mexico. REAL will continue operating domestic lines in Brazil and routes through Asuncion, Montevideo and Buenos Aires.

Pan American World Airways is to divest itself of its 50 percent stockholding in Pan American-Grace Airways (Panagra) under a New York Federal District Court judgement. Pending the divestment, under conditions to be determined by CAB, Pan Am must not interfere with any Panagra applications to CAB for route extensions or changes. PanAm plans to appeal the ruling. Balance of Panagra stock is owned by W.R.Grace & Co.

General Dynamics' San Diego Division and the USAF have carried out a series of drop tests on the new two-component bomb and fuel pod for the Convair B-58 Hustler *at speeds of up to Mach 2. Picture shows the lower component on its handling trailer with the upper component already mounted under the aircraft. Flights were carried out from missile ranges in Nevada and New Mexico at altitudes up to 40,000 feet.*



American Airlines has announced an order for 25 three-jet Boeing 727s for delivery in 1964. Boeing's order book for the 727 thus stood at 117 aircraft at mid-May.

British independent Cunard Eagle Airways has confirmed an order for two Boeing 707-465s (Rolls-Royce Conway by-pass engines) for delivery in early 1962 and has taken an option on a third. Contract value including spares is £6 million. Cunard Eagle will operate the 707s in first and economy class configuration on Atlantic routes.

British European Airways reports an estimated profit of £1.25 million for the financial year ended March 31st, 1961, a considerable drop on the 1959/60 figure of £2 million and representing only 3 percent on turnover. BEA carried 3,990,957 passengers and 150,000 tons of freight and mail. *British Overseas Airways Corporation* will show a deficit of approximately £1.7 million for the year after taking into account a deficit of about £1.8 million on the investment in its eleven associated airlines. BOAC's own operating profit was £4,750,000 for the year but interest payments will leave a surplus of some £100,000 for the year. Traffic was up 30 percent for the year with traffic revenues totalling £88.5 million.

British independent Skyways Coach Air Ltd. has signed a firm contract with A.V.Roe & Co. (HSG) for three Avro 748 turboprop feederliners. First delivery is scheduled for autumn 1961 for route proving, and the other two will be delivered for introduction into service in spring 1962.

Sabena is operating Boeing 707-329s and *Caravelles* to provide jet service to thirty points on the route network this summer (and *not* DC-8s as printed in error on page 501 of Interavia No. 4/1961).

INDUSTRY

Bölkow Apparatebau of Munich is negotiating with Fiat of Turin regarding Italian licence production of the Bö 810 *Cobra* anti-tank missile which has been satisfactorily tested by the Italian artillery at the Nettuno (Rome) centre. Bölkow is also talking with the Italian Air Force concerning possible adoption of the Bö 102B *Heli-Trainer* which has already been evaluated by the Italian Air Force.

British Aircraft Corporation has booked an order for five BAC.111 short-range jets for U.S. feeder operator Ozark Air Lines. A firm contract is expected shortly valued at $11.5 million with delivery scheduled for 1965. Continental Airlines is also interested in the BAC.111 and a decision is expected by mid-summer.

Sud-Aviation President Georges Hérell has said that the supersonic *Super-Caravelle* will come into service in 1967-68. A mockup and plans of the new aircraft were shown to French Transport Minister Robert Buron last month.

Savino Bianchi has been named President of the Italian company Magneti Marelli, succeeding Count Bruno Antonio Quintaville who has resigned. Mario Zavattaro and Egidio Troya are Joint Assistant General Managers.

Canadair is developing a refrigerated container for transportation of chilled meat, fruit and vegetables in the CL-44 swing-tail freighter. Each container will have its own refrigeration unit and will be completely self-contained permitting the degree of chilling to be varied to suit the cargo.

The Boeing Company is the new name voted by Boeing Airplane Company stockholders to reflect increased diversity into non-aircraft fields. Boeing's first quarter sales were down from $395.7 million to $325.2 million primarily due to reduced deliveries in the period arising from model changes on the B-52 bomber and *Bomarc* missile programme. Company spokesmen say 1961 earnings could be as high as $32 million.

General Dynamics Corp. has created five new operating divisions all formerly components of the Convair Division: GD Astronautics; GD Fort Worth; GD Pomona; GD San Diego and GD Daingerfield. Convair General Office at San Diego, Calif. is eliminated and key personnel re-assigned to corporate staff or operating divisions. C.Rhoades MacBride will be responsible for the five new divisions plus General Atomics Division, with headquarters in San Diego.

MILITARY AFFAIRS

West Germany is negotiating for direct supply of a further batch of 75 F-104G *Starfighters* from Lockheed Aircraft Corp. to speed build-up of operational units. The European production programme would reportedly be cut by 75 aircraft. Lockheed direct supply to Germany would thus total 201 aircraft (30 F-104Fs and 96 + 104Gs).

U.S. Army has approved purchase of the French wire-guided ENTAC anti-tank missile to replace the Nord-Aviation SS.10 weapon currently operational with U.S. infantry divisions, but the Nord-Aviation SS.11 is still under active evaluation by the Army for airborne (helicopter) usw. The U.S.Marine Corps is expected to follow the Army lead. ENTAC is manufactured by Direction des Etudes et Fabrications Aéronautiques but Washington sources say that Nord-Aviation may share in production.

U.S. Navy is giving increasing attention to integration of launch and control equipment for different shipboard missile systems. Separate launch, control and other associated support requirements are expensive and uneconomical in space utilization and personnel. The long-range trend towards shipboards automation spurred by the continual problem of retaining personnel with high technical skills would also benefit. One possibility is development of common launch and control equipment for the *Tartar* surface-to-air missile and the *Asroc* surface-to-underwater rocket, both equipping destroyer-type vessels. Navy R&D officials are impressing upon industry the need for bigger jumps in the weapons improvement cycle, and less devotion to mere product refinement.

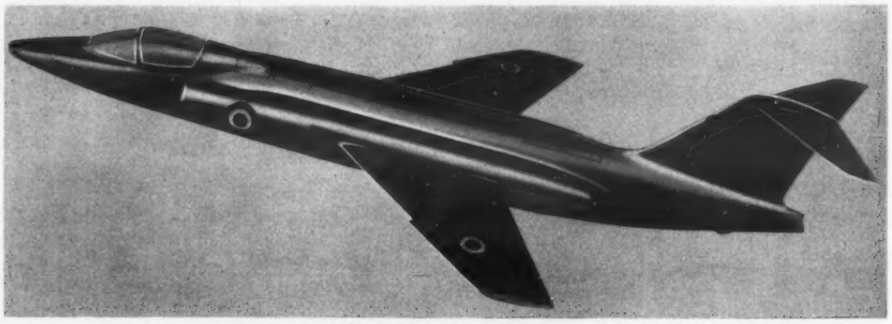
Major *Skybolt* ALBM problem is still the development of an effective pre-launch guidance computer. In common with all mobile missiles (i.e. *Polaris* and railroad *Minuteman*), *Skybolt* must be fed data giving precise location in relation to the target. With *Skybolt* the problem is magnified by the speed of the B-52H carrier and the resulting difficulty of continuous injection of revised guidance data into the missile on a real-time basis. Despite intensive work on the problem and development of the highly-accurate SINS (Ship's Inertial Navigation System) the U.S. Navy is still seeking increased accuracy in its *Polaris* pre-launch guidance technique. Observers expect the USAF and the contractor team headed by Douglas to produce an adequate system in time for *Skybolt's* scheduled operational date in 1964.

The U.S. Navy's new Lockheed P3V-1 Orion *ASW aircraft will carry a crew of ten on missions lasting over eight hours. Cruise speed is reportedly over 400 m.p.h. and military loading will include nuclear depth charges, torpedoes and rockets. Powerplant is four Allison 501-D13A turboprops. Lower picture shows mockup of the interior.*

Italian Defence Ministry has set up a Technical and Scientific Council for Defence to integrate and control the three armed services' research and test programmes in the technical and scientific fields. The Council will consist of a Permanent Committee and a Permanent Technical Secretariat and will be headed by a Chairman appointed by the Defence Minister from one of the three services. Membership will include the three Deputy Chiefs of Staff and six technical members. The Permanent Committee, comprised of a Chairman and three Chiefs of Staff' technical nominees,will submit research and test programmes and costings to the Council.

Kuwait Government has confirmed an order to British Aircraft Corporation for six Hunting *Jet Provost* trainers to form the nucleus of the Kuwait Air Force. Kuwait personnel are currently in the U.K. for training with the RAF. Maintenancee of the *Jet Provosts* for the Kuwait Air Force will be handled by the Bristow Company.

Aviolanda Aviobridge, *shown here at Amsterdam-Schiphol Airport, is a telescopic covered gangway extending from terminal exit to aircraft loading door. Designed to fit practically all types of modern aircraft, three telescopic sections permit extension to between 50 and 100 feet from either the wall of the terminal building or finger dock. Vertical adjustment is provided by a hydraulic supporting vehicle under the second section of the bridge.*



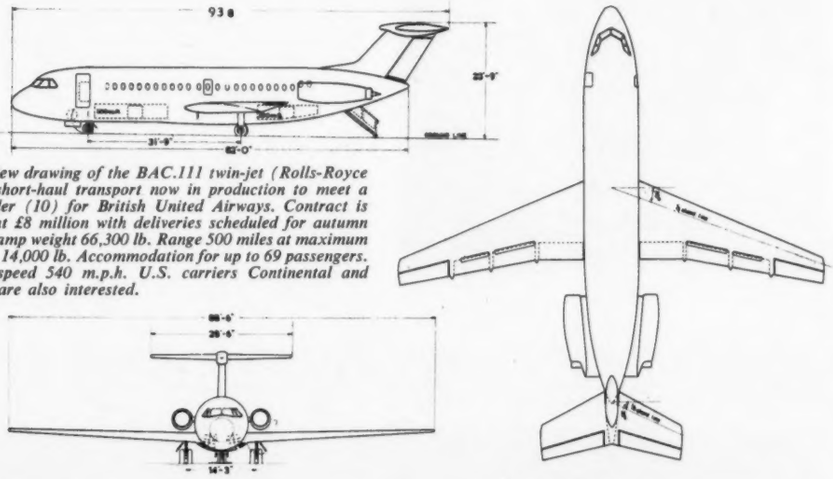
A model of one version of the Fiat G.95 V/STOL tactical fighter project submitted to NATO. Based on a series of Fiat patents by Professor Gabrielli and developed from the G.91, Fiat proposes one or more turbojets for propulsion plus several auxiliary lift engines for very short or vertical take-off.

Australian plans for licence production of the thirty Dassault *Mirage IIIs* on order for the Royal Australian Air Force schedule delivery of the first aircraft in 1963 with the first squadron in operational service about twelve to eighteen months later. On current form, the Australian production programme will be almost entirely concerned with assembly. A few aircraft will be imported complete except for final check-out, with the balance of the initial ten constructed from major component sub-assemblies off the Dassault production line.

AIRCRAFT, POWERPLANT AND EQUIPMENT

British Executive and General Aviation Ltd., in addition to the four-seat *Airedale* (cf. page 554, Interavia 5/1961), is offering the Beagle-Auster A61 *Terrier,* a development of the Auster *Mark 6* powered by a 145 h.p. de Havilland *Gipsy Major 10.* Price for standard version is £1,995. Span 36 ft; length 23 ft 3 in; wing area 184 sq.ft; empty weight 1,636 lb; disposable load (pilot, passengers, 522 lb of baggage and 22 Imp.gals. = 192 lb of fuel) is 714 lb; maximum all-up weight 2,350 lb. Maximum sea level speed 123 m.p.h.; economic cruising speed at 1,000 ft is 104 m.p.h.; range with normal payload 385 miles; service ceiling 14,000 ft; sea level rate of climb 810 ft/min; take-off distance to 50 ft is 235 yds.

The Dassault Mirage IIIE strike aircraft made its first flight at Melun-Villaroche on April 5th. The aircraft is powered by a SNECMA *Atr 9C* jet engine with an automatic device for providing short bursts of 6,400 lb thrust at Mach 1.4. The *Mirage III* is now in production at Dassault's Argenteuil and Bordeaux-Mérignac plants and French Air Force interceptor squadrons should receive first deliveries this year.



Three-view drawing of the BAC.111 twin-jet (Rolls-Royce Spey *) short-haul transport now in production to meet a first order (10) for British United Airways. Contract is valued at £8 million with deliveries scheduled for autumn 1964. Ramp weight 66,300 lb. Range 500 miles at maximum payload 14,000 lb. Accommodation for up to 69 passengers. Cruise speed 540 m.p.h. U.S. carriers Continental and Braniff are also interested.*

A prototype of the Breguet 1150 Atlantic *naval reconnaissance and ASW aircraft during final assembly at the Toulouse-Colomiers facility (see also Interavia No. 5/61, page 604 for three-view drawing and details).*

The Morane-Saulnier MS.885 Super Rallye (third prototype of the Rallye series) made its first flight at Villacoublay on April 20th. Powerplant is a 145 h.p. Continental engine. On completion of flight tests the aircraft is going to the United States for a demonstration tour.

Third prototype of the Merckle SX 67 began flight tests on April 12th. The five-seat SM 67 helicopter has been developed by Merckle Flugzeugwerke GmbH of Bad Friedrichshall under a Federal contract, and is powered by a Turboméca *Artouste* shaft turbine.

Progetti Costruzioni Aeronautiche SpA (Procaer) of Milan plans to build two new versions of the F.400 *Cobra.* First is the F.480 military training and liaison aircraft (one Turboméca *Marboré VI* of 1,060 lb thrust), designed for a maximum speed of 360 m.p.h. and an endurance of three hours. Second version, designed for civil applications, is designated F.600 and powered by two 660-lb-thrust jet engines. This four-seat model will have a maximum speed of 390 m.p.h., take-off weight 5,510 lb, payload 2,590 lb and an endurance of three hours.

First Kanpur-built Avro 748 is still officially expected to fly in "mid-1961" but reports from India suggest October as the earliest possible date. Production of four aircraft a month is planned for 1962.

First flight model of the Saturn booster made its first static run with all eight engines firing at the end of April (in earlier experiments, test versions of the booster were used). The powered phase lasted 30 seconds, the thrust obtained being 1,320,000 lb. During a further static run at Huntsville on May 11th, a maximum thrust of 1,315,000 lb was obtained with a firing lasting 111 seconds. The booster will be sent to Cape Canaveral by barge later this year for flight testing.

Avco Lycoming Division has received FAA type certification for two new engines with fuel injection. The six-cylinder 350 h.p. IGO-540-B1A with Bendix RS10ED2 injector has a consumption of 18.5 U.S. gals. of fuel per hour at 75 percent rated power, and 13.5 U.S.gals. at 60 percent. First installation of this type will be in the *Aero Commander 680F.* The second is the four-cylinder, 180 h.p. IO-360-B1A fitted with Simmonds injector, to power the Beech *Travel Air.*

Société d'Etudes et Fabrications Aéronautiques (EFA) of Clichy, is manufacturing pressure suits and helmets for pilots of the Dassault *Mirage III* supersonic fighter. With somes slight modifications, this equipment is also suitable for pilots of the Lockheed F-104 *Starfighter* equipped with British or U.S. ejection seats. EFA has developed a new type of pressure-tight helmet with a ball-bearing system at the point of attachment to the suit and a visor. The company is also developing a pressure suit for astronauts.

United States Rubber Company of New York has developed special shock bags for the Fairchild AN/USD-5 reconnaissance drone. Manufactured of rubber-coated nylon and resembling large oil drums, the bags are packaged in the wings and nose of the drone for release by parachute and inflation at a pre-set height. On impact with the ground, blow-out disks release the gas, enabling the drone to settle slowly into the ground.

SPACE RESEARCH AND MISSILES

Commander Malcolm D.Ross and Lieutenant Commander Victor G.Prather Jr., of the U.S.Navy made an ascent in a high-altitude research balloon (Stratolab High No. 5) on May 4th. Object was to record physiological data on the two officers in the stratosphere and to test pressure suits at temperatures of — 65° F. An altitude of 113,500 ft was reached two and a half hours after ascent from the carrier *Antietam* in the Gulf of Mexico (previous high altitude for a manned balloon was 102,800 ft). Commander Prather lost his life during the helicopter recovery operation from the ocean.

Project Bimbo is the USAF designation for a solid-propellant booster to lift a rocket vehicle the size of *Saturn* to a height of 60 miles or to put the *Dyna-Soar* space glider into orbit. Thrust will be in the order of 3 to 5 million pounds and many special features will include vector control and a lightweight case. If development authority is forthcoming, the USAF could put *Bimbo* into production in 1963. Aerojet-General and Grand Central Rocket Co. are engaged on studies. ⟷

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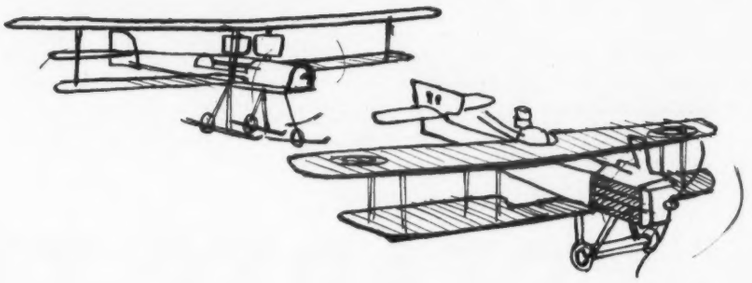
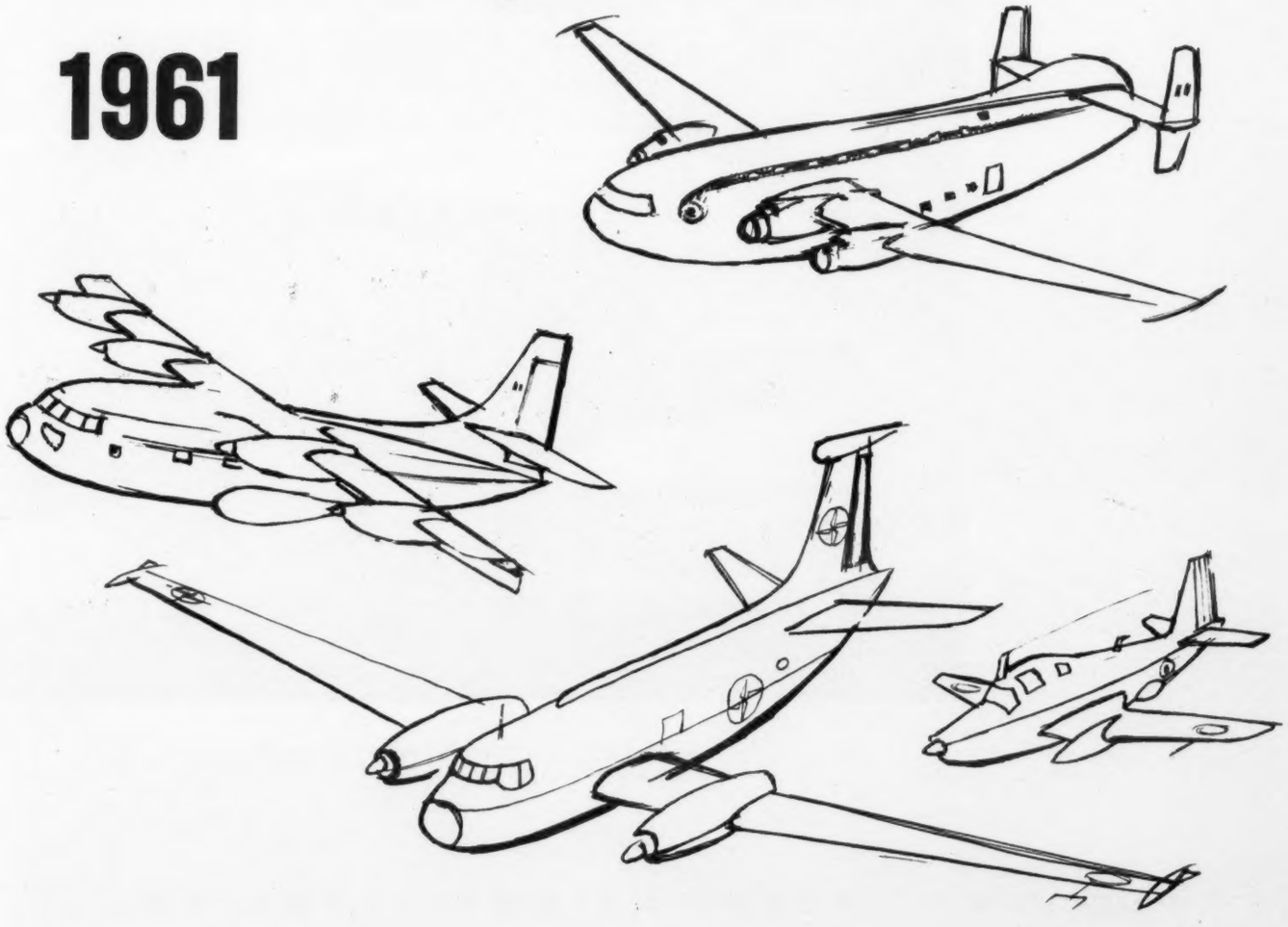


fifty years in the service of aviation

1911

Louis Breguet

1961



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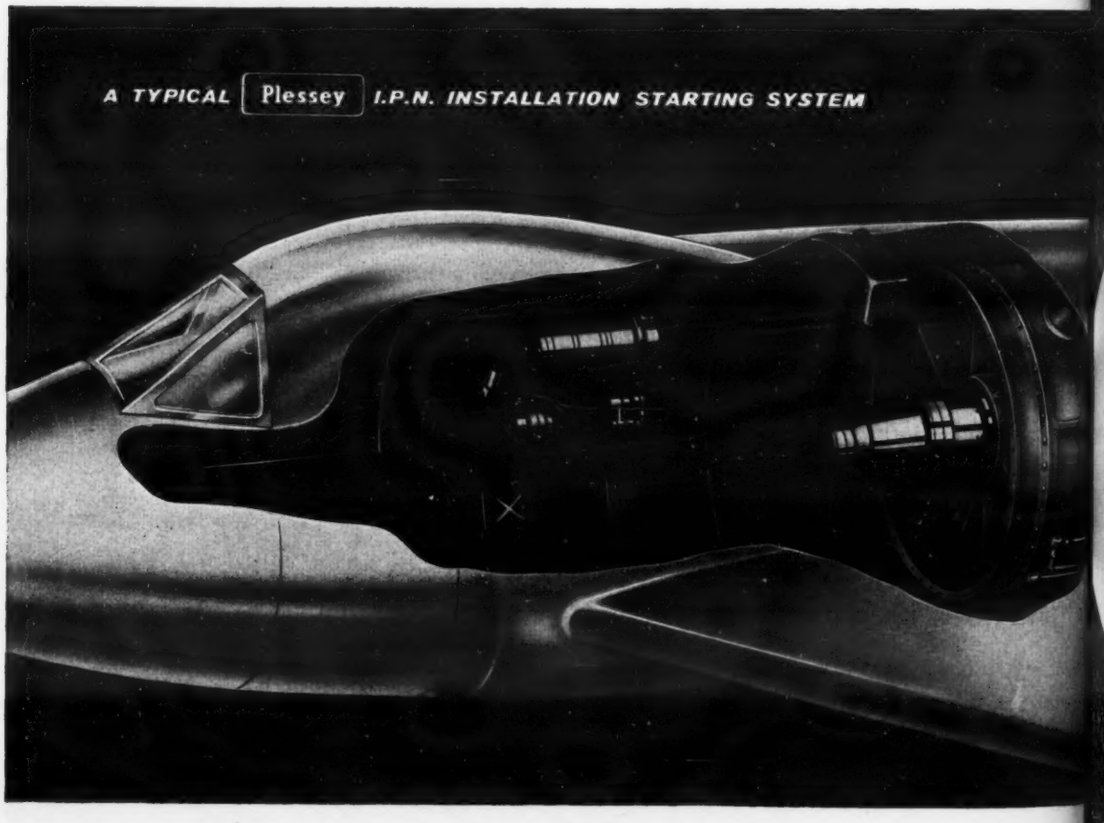

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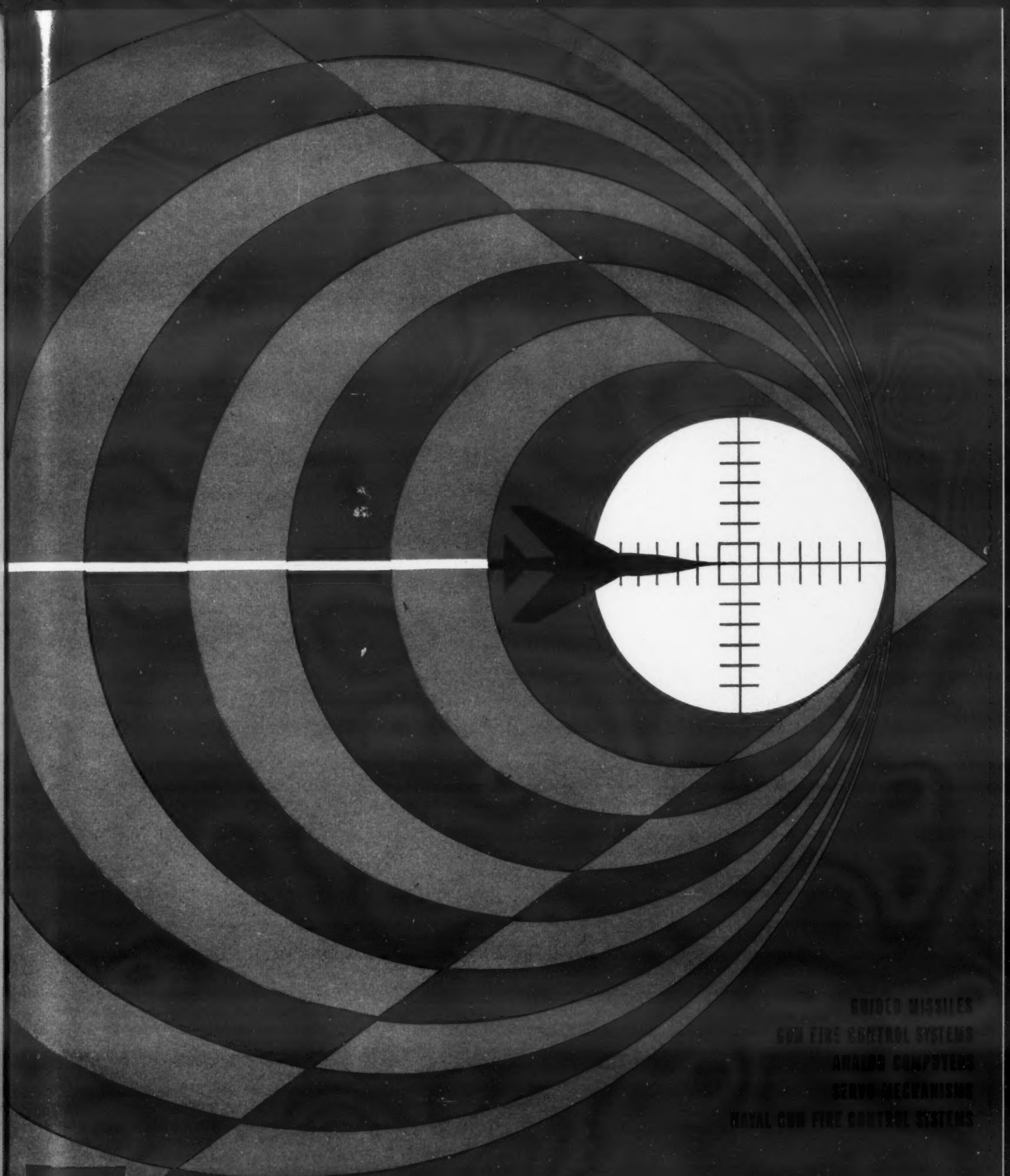

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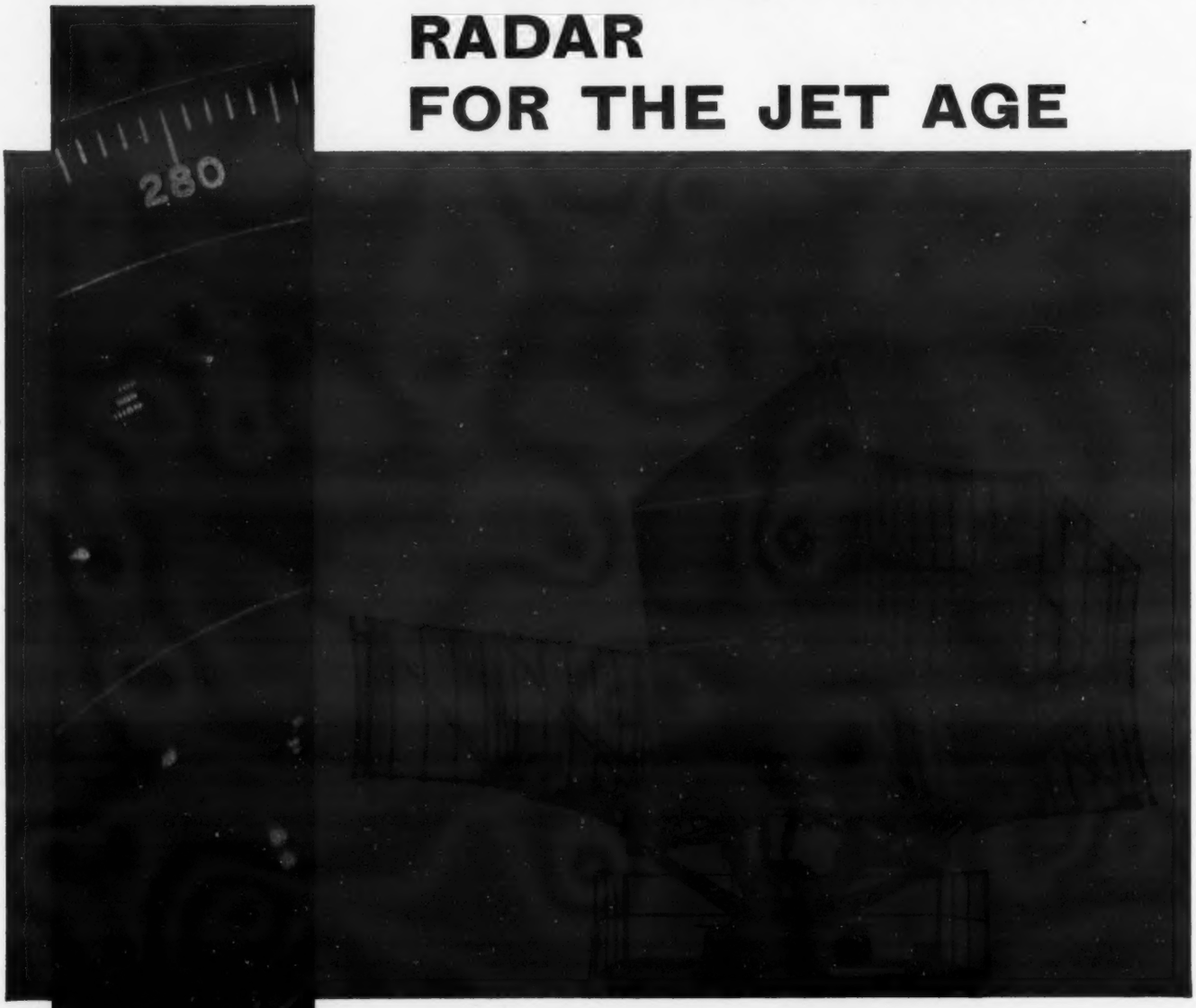

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Undercarriages, Brakes and Tyres

At least 5% of the take-off weight of a modern aircraft is accounted for by the undercarriage—including actuation and control devices, hydraulic lines, airframe reinforcements etc. For a long-range airliner, a considerable portion of whose useful load is taken up by fuel, this is equivalent to about half the payload. Where prices are concerned, the comparison is still less favourable. And this enormous expense is incurred for a few minutes of each flight: take-off, landing and a few miles of taxiing. But aircraft have to operate both in the air and on the ground. And as the design of any aircraft is primarily aimed at obtaining an optimum aerodynamic configuration, its requirements while it is on the ground must of necessity take second place. This increases the problems facing the undercarriage designer, who must leave no stone unturned in meeting the wishes of the airframe manufacturer.

In both civil and military sectors, aircraft development has been, and still is, characterized by a continual increase in weight and performance, i. e. speed. This has led to increasingly high wing loadings and correspondingly higher landing speeds. And the demands made on an undercarriage, particularly on the brakes, increase roughly linearly with weight and are squared as landing speed increases. It is hence scarcely surprising that undercarriage construction has become a science on its own, which today occupies entire industries.

In the undercarriage sector, as in many others, aviation techniques have benefited other branches of industry. One has only to think of light construction or—to stick to the undercarriage—of disk brakes, which were originally developed for aircraft and are today being increasingly used in the automobile industry. The same applies to tyres, shock absorbers and hydraulics.

Improved lift devices and thrust reversers have, it is true, of late relieved the burden on the undercarriage. But the appearance of new formulae—combat and transport aircraft operating from makeshift bases, V/STOL aircraft—has confronted undercarriage builders with difficult problems which are keeping their research and experimental departments fully occupied.

The following articles from two prominent undercarriage manufacturers introduce a series which will be continued in forthcoming issues. ↔

Landing Gear Developments by Bendix

In the 1950—1960 period, the wheel load capacity for a given area envelope has increased two and one half times, and brake capacities have increased at an even greater rate. In the same 10-year period, airplane manufacturers have seen a 500% increase in brake performance. These are certainly impressive achievements, but even greater improvements are under development.

Bendix is designing and testing brakes that use the excellent heat storage capacity of beryllium. Another striking advance could be seen in the use of the latent heat of vaporization of water. These developments are being pursued in order to be prepared for the future. The increase in wheel capacities by the use of aluminium and magnesium forgings will be complemented by the higher temperature capacity of titanium and steel. Design and manufacturing experience is being gained rapidly, and soon wheels using these materials will be ready for service in aircraft.

Air/oil shock absorption techniques have proved very satisfactory for current aircraft, and the use of heat treated steels in the 280,000 to 300,000 psi UTS range has provided shock struts which weigh much less than earlier models. Future developments lie along the lines of further weight reduction by precisely scientific utilization of the materials. To satisfy high temperature conditions, mechanical deformation energy absorption techniques, as well as skids, are being actively considered.

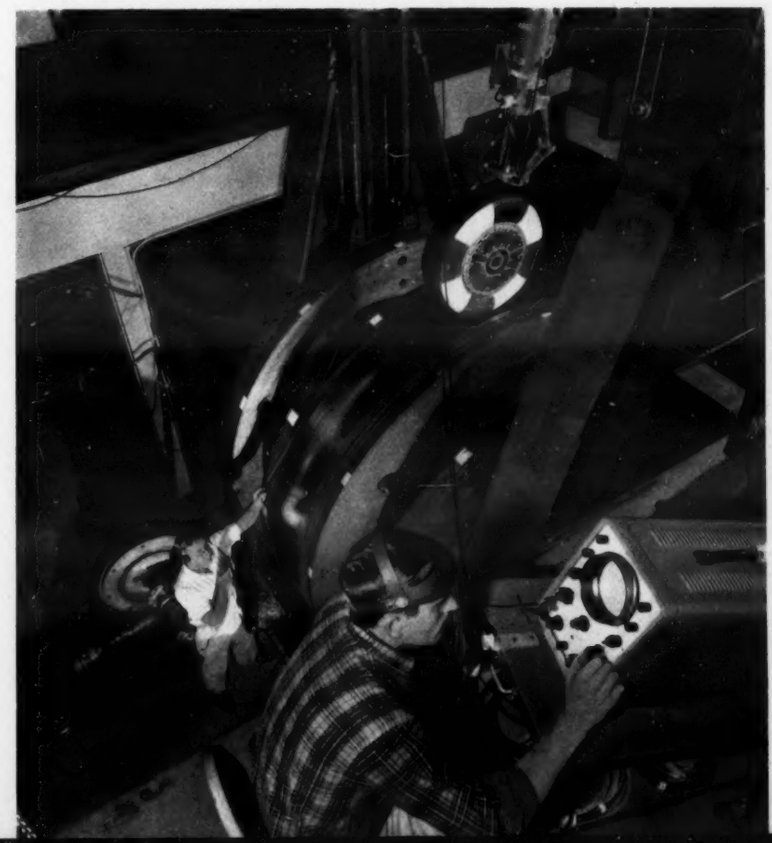
Mechanical design ingenuity is most important in landing gears. The invention of torque link steering is an excellent example of this; here steering cylinders contribute to the torsional stiffness of the gear, thus reducing the total weight of the nose gear system. Other examples of landing gear accessory developments can be seen in brake control systems. The Bendix Corporation has provided hydromechanical and electromechanical open loop braking systems to the aircraft industry. To meet the ever increasing performance requirements, closed loop braking systems are under development.

Heat dissipation problems

In brake design, heat is the most important consideration. To find a friction material capable of withstanding higher heat conditions, considerable development effort provided a ceramic-metallic combination now known as *Cerametalix*, which allowed high temperature operation, and thus higher capacities. It also increased life and allowed higher friction material pressures. The use of *Cerametalix* then created a heat problem for the rotating members of the disk brake, to which an excellent solution was found in the segmented rotor, which is now available in several configurations. Heat must be considered in all parts of the brake, and heat flow paths are experimentally and analytically determined. Coatings, insulators, seals, and materials are all selected to provide the best heat balance, which has proven successful in the many brakes that are produced.

Heat is also important in wheel design. Tire blow-out hazards have been greatly reduced by incorporating fuse plugs which deflate the tire before it has weakened to the point of exploding.

Bendix technicians carrying out undercarriage trials on the combination drop test-dynamometer. The landing gear strut and wheel are lowered on to the rotating flywheel to simulate landing conditions.

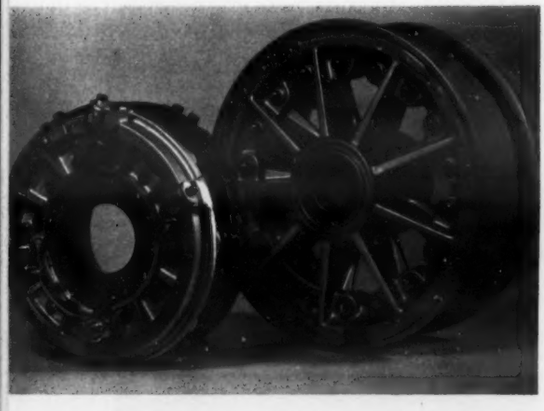


A numerically controlled milling machine installed at the Bendix plant. The cabinet at the right of the picture contains the tape playback machine which controls the programmed sequence of operations.

A wheel fuse plug is a simple device, made of a material which melts at a temperature of approximately 300 °F, i. e. just below the critical temperature of a nylon tire and well below the critical temperature of the wheel. Three or four plugs are spaced about the wheel, since it is the top portion of a wheel at rest which is hottest. By reducing the danger of explosions, this constitutes a major safety factor. Material selection and utilization are the keys to developing a highly efficient structure, magnesium and aluminium alloys being forged to the minimum section thickness that fatigue requirements will permit. A further important detail in wheel design is the provision of protective coatings and insulating shields.

Imaginative mechanical design is the stock-in-trade of the landing gear designer, for space, weight and cost must be held to the minimum. Unique retraction schemes offer considerable weight savings, and the extensive use of the cantilevered type of undercarriage in place of the heavier levered type has decreased the space required. Such developments as the frequency sensitive shock absorber, the internal shock absorbing wheel, etc. have refined the designs still further. Steering mechanisms that are suited to any aircraft design are available at Bendix, including the famous torque link design, the rotating collar type and the 360° swivel type. These systems are available with electrical feedback servo control or mechanical feedback control. Another very popular accessory is the electro-mechanical anti-skid system, made by the Pacific Division of Bendix, which permits pilot control to the point where skidding is imminent and then reduces brake pressure just enough to prevent it.

Forward thinking manufacturing techniques have contributed to the development of Bendix landing gear equipment. The capacity of the forged wheels has been greatly increased, and techniques such as roll burnishing the bead seat area of the wheel have increased fatigue life. Operations such as turning, drilling and boring have been tooled for minimum cost, and an array of unique production schemes has been developed for strut production methods. The flash welding of large diameter tubes also required development and now permits more efficient products. A recent programme, using numerically controlled milling machines, has proved a great cost saver, as these machines require a reduced time for setting up and produce higher quality parts. Capacities for large quantity production are available in addition to the versatile prototype shop.



The wheel and brake of the F-104. Details of the brake stator and rotor assembly can be seen on the left.

A brake assembly undergoing tests. The effectiveness of the heat shielding is demonstrated by the concentration of heat in the inner segments of the wheel.

Performance simulation and testing

Realistic testing has played a major role in the development of landing gears, the most notable item of equipment being the combination drop test-dynamometer, in which an assembled gear, including accessories, can be tested to realistic aircraft conditions. By dropping the gear system on a rotating flywheel all inertia forces are imposed and then, by stopping the flywheel with the brakes, the dynamic forces are again simulated. Bendix has developed techniques of simulating shock struts which are too large to be mounted; by means of an equivalent mass-spring system, the airplane performance can be predicted analytically. This testing has been extremely valuable in cases of nose gear shimmy and main gear oscillation due to braking.

Many other test equipments are to be found in the Bendix laboratories. For example, there are three drop test rigs with capacities for testing the very small to the very large. As the existing laboratory equipment did not provide realistic conditions for testing the steering and braking systems, an aircraft was purchased and equipped with adequate instrumentation to test these systems fully, for realistic testing is essential to satisfactory product performance.

Equipment for the F-104

Landing gear design activities began at South Bend, Indiana, in the early 1920s, and a long history of products exists there. There were the shoe type brakes and bungee cord and leaf spring landing gears. Early strut designs were primarily welded tubes, the wheels mostly castings and greatly overdesigned in comparison to today's design parameters. A current example of Bendix wheel and brake equipment is that manufactured for the F-104 *Starfighter*, and described below in detail.

The wheel is a 26 × 6.6 size and has two halves tied together with high strength bolts. The inboard half is machined from an aluminum alloy forging, whilst the outboard half is forged magnesium. This wheel has a heat shield made of thin stainless steel, which serves to effectively retard heat flow into the wheel, and has reduced temperatures by 30 percent in the 200° to 300 °F range. A fuse plug, located in the critical temperature area, is constructed of a close tolerance melting point alloy. The wheel has a radial load capacity of 13,000 lb and a design roll life of 1,000 miles.

The brake is a three-rotor design which features the Bendix *Cerametalix* friction material and the segmented rotor, each rotor being made up of six segments held in position by a rotor spider and the stator plates, positioned between the rotors, carrying the friction material. This material is put into cups which are then riveted to the stator plates, thereby adding structural rigidity; the pressure plate and backing plate also carry *Cerametalix* friction material. Four friction type automatic adjusters are provided on the F-104 brake, the adjuster maintaining a constant fluid displacement during service and also allowing visual inspection of lining wear without wheel removal. This brake is designed to dissipate 5,025,000 ft lb of kinetic energy for 50 stops.

This wheel and brake equipment has seen considerable service in the U.S. Air Force and has a history of smooth and reliable performance. The details of its design are indicative of the progress in current brake development. ⟶

Military Requirements and Undercarriage Design

By René Lucien, Chairman and Managing Director, Messier S. A., Montrouge

In the first few years following World War II, all military specifications, in so far as they referred to the aeronautical industry, culminated in the demand for maximum flight speed—both in horizontal flight and in climbing. It was then thought that it would be possible to put up with the fact that aircraft needed longer and longer, and therefore very vulnerable, runways. European defence was accordingly based on relatively few operational bases, with miles of concrete runways, and only 18 aerodromes were suitable for use as bases for retaliation measures.

Following the desires of the military planners, the airframe constructors shaped their designs to lowest possible air resistance and reduced fuselage section and wing thickness to a minimum. This in turn led to undercarriage constructions which were extremely economical in space and weight.

At that time undercarriages were built in high-tensile light metal alloys and alloyed steels, with a tensile strength of up to 185,000 p.s.i. It goes without saying that wheels in particular were kept as small as possible. In other words, the maximum tyre pressures which the state of development appeared to permit for landing on good concrete runways, namely 266-300 p.s.i., were taken as the basis.

However, the development of high-accuracy guided missiles, which are practically unintercepticble, obliged the strategists to admit that protection of the operational bases could no longer be assured, and they called for aircraft which could manage on makeshift airfields in the vicinity of the battle zone and avoid attack by dispersal.

This demanded undercarriages which could safely taxi, take off, and land on uneven ground. The fact that the wing loading of the aircraft was continually on the increase and that landing speeds were of the order of 150 m.p.h. certainly did nothing to lighten the tasks of the undercarriage constructor.

A further complication was the fact that a completely new approach was called for, not only in the case of undercarriage configuration, but also of loading assumptions. There was, however, little or no experience available about the stresses which occur in take off, touchdown and taxiing on various types of ground. And in the absence of such experience investigation could not be confined to a few typical cases, but a complete spectrum of all critical stresses had to be established.

Last but not least, account had to be taken of the fact that aircraft land on short airfields at a high angle of attack. This calls not only for higher main landing gear struts but in addition for a sturdy nosewheel to give the aircraft stability, and highly efficient brakes, which are in practice fully loaded every time a landing is made.

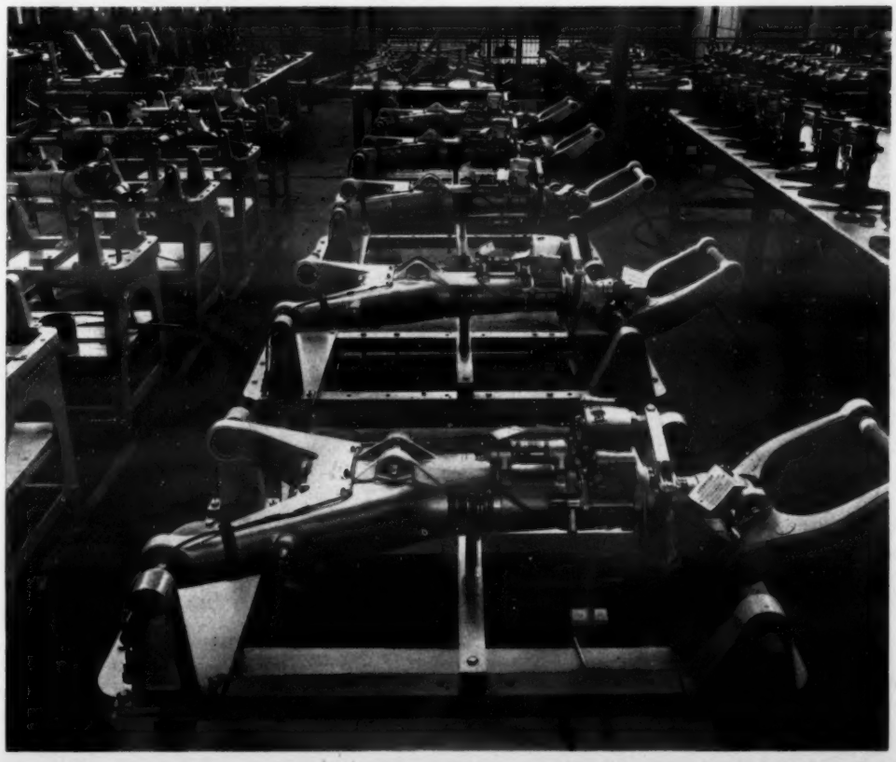
It seems appropriate to illustrate the chronological development of undercarriage construction by means of three typical examples, namely the fighter interceptor, restricted to well-constructed concrete runways, the strike aircraft, developed for operations near the front, and finally the multi-purpose high-performance combat aircraft (Mach 2+).

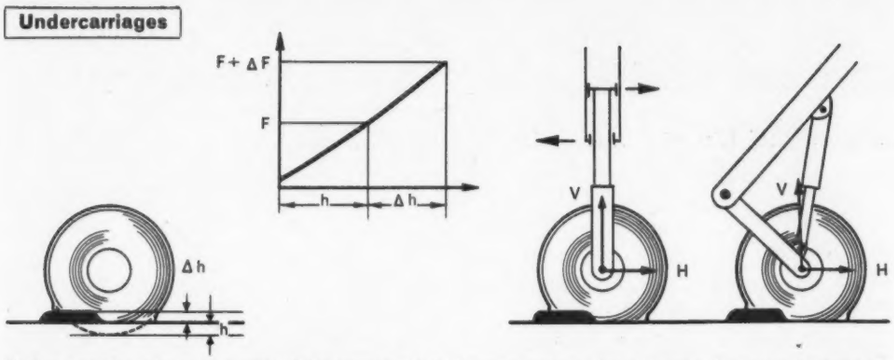
Stage 1: The concrete-bound fighter-interceptor

The Dassault SM-B2 *Super Mystère* supersonic interceptor, in use with the French Air Force, may be taken as a typical representative of this first stage. The construction of the undercarriage for the *Super Mystère* did not give rise to special difficulties, as we had already accumulated experience with this type of undercarriage from similar aircraft. Nevertheless, it is worth mentioning one phenomenon which caused us considerable headaches in the *Mystère IV,* the forerunner of the SM-B2, as it throws light on the importance of vibrations in modern techniques. Whilst the brakes gave rise to no complaints either in the prototype or in the pre-series production of the *Mystère IV,* in the series production vibrations manifested themselves from the start, and always as the result of actuating the brakes. These vibrations were so strong that they put the operational capability of the aircraft seriously in doubt. In order to trace the cause of these unpleasant manifestations, we decided first of all on a thorough frequency analysis, and we investigated in the first place the relationship of the inherent frequencies of the undercarriage to those of the wings and of the complete aircraft. Our hope of being able to eliminate these vibrations by varying the inherent rigidity of the undercarriage proved illusory. We constructed first a lighter and then a heavier undercarriage, but the change in inherent frequency—which, as is well known, is proportional to the square root of the weight—did not suffice to disperse the resonance.

This led us to the idea of looking for the cause of trouble in the brakes themselves, with their vibration-generating effect. Could the problem be solved by reducing the periodic energizing forces? Surprisingly large amplitudes did indeed show up in the oscillograms of the vibrations occurring in the brakes as a result of friction. This showed the way, and considerable progress was achieved by improving the friction surfaces on the disks and by a rearrangement of the shoes. After some months of intensive testing, there appeared, instead of the wide amplitude sine wave, a steady line with only mere traces of vibrations. And on the aircraft itself, all vibrations vanished as soon as the brakes were applied. Satisfactory as the result was, we had still not ascertained why the resonance had occured only in the series model and not

Assembly of nosewheel undercarriages for the GAMD *Mirage IIC* single-seat multi-purpose combat aircraft at the Bidos works of Messier S. A.





Passing over an obstacle. As a result of the mass inertia of the undercarriage, first of all only the tyre undergoes additional compression by the mass Δh (*a*) (*h* being the flattening under the static load), while wheel and oleo leg remain in position. The additional compression Δh not only results in an additional vertical force ΔF (*b*), but also considerably increases the horizontal force ΔH exerted by the ground on the wheel. With straight oleo legs, this leads to increased friction within the oleo leg (*c*), while the wheels of trailing arm undercarriages deflect backwards and upwards in the plane in which they are moving (*d*).

in the prototypes. It took, months before the riddle was solved; we learnt by chance in conversation that, as a result of a modification in the airframe, the wing of the series model was nearly 450 lb lighter than in its predecessor.

This experience shows the importance of close cooperation between airframe and undercarriage constructors.

The design and articulation of the *Super Mystère's* undercarriage will emerge from our comparison, but a few brief complementary details may not be out of place here. The main undercarriage struts are of chrome-molybdenum steel of 184,900 p.s.i., tyre pressure 266 p.s.i.; the oleo leg retracts into the thin wing, the wheel into the fuselage. Nosewheel gear and oleo leg, tyre pressure 216 p.s.i., support frame forged in aluminium alloy, wheel turns through 90° on retraction and lies flat in the fuselage.

Special care was necessary in the design of the brakes, for which only a little space was available in the small 14-inch wheels. On the one hand the weight had to be kept low, but on the other hand the brakes had to be capable, in the case of an unsuccessful take-off, of bringing the aircraft from 125 m.p.h. to stop in a very short distance, corresponding to 4,000,000 ft lb per brake.

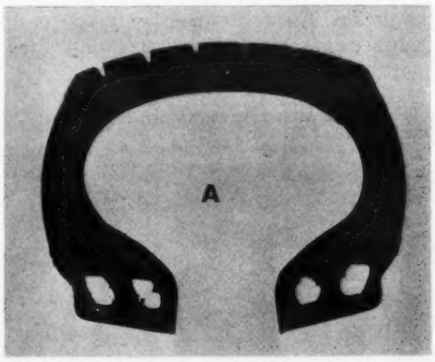
When the *Super Mystère* is operating on well-maintained concrete with a theoretical unevenness equal to about one inch, no difficulties appear either in landing, taxiing or take-off.

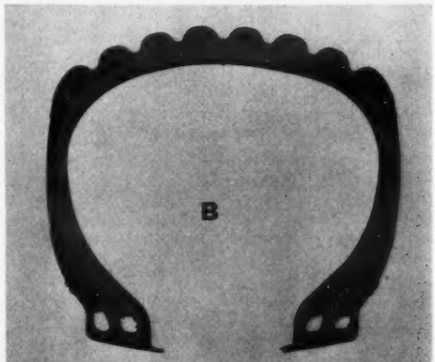
Stage 2: The "cross-country" strike aircraft

New problems confronted the undercarriage constructor when NATO invited offers for a light combat aircraft to operate from makeshift airfields. The specifications called for a landing weight of 7,700 lb at tyre pressures of 50-83 p.s.i. This made it essential to install relatively large wheels in small aircraft, whose frontal area had to be kept down to a minimum, for flight speed just under the sound barrier.

Four competitors presented themselves for the NATO flight trials at Brétigny, namely the Breguet *Taon,* the Dassault *Mystère 26* and *Mystère 24* (from which the *Etendard IV* was later developed) and the Fiat G.91. The configuration of the undercarriage was left to the individual constructors, although it had to conform to given specifications.

Whereas Dassault preferred a classical telescopic leg for the main undercarriage, Fiat and Breguet decided in favour of a trailing arm undercarriage. The three competitors were unanimous in the matter of the nosewheel and opted for the trailing arm—which, in our opinion, is absolutely imperative in a "cross-country" aircraft. The nosewheel undercarriages are moreover similar in construction, with swivelling forks or half-forks, independent shock absorbers, and retraction to the rear with the aid of a retraction strut. Amongst the materials used for stress-bearing parts are cast magnesium alloys, wrought aluminium alloys and steels with high tensile strength (185,000 p.s.i.). To go further into the details of these various undercarriages is beyond the scope of this article.





Section through a Kléber-Colombes high-pressure tyre (*A*) and a medium-pressure tyre (*B*). Tyre *A*, with a gently curved tread, equips the GAMD SM-B2 *Super Mystère*. The high tyre pressure of 266 p.s.i. ensures safe landing only on good concrete runways. Tyre *B*, designed for the main wheels of the GAMD *Mirage IIC*, has a so-called "laminar profile," whose nylon-reinforced treads ensure high rigidity of the outer layers.

No important shortcomings were revealed in the course of tests, and all the aircraft came off well, within the terms of the competition. The landing characteristics were tested on the emergency runway at Brétigny, whose grass surface was flat and in excellent condition.

Apart from the undercarriage constructor, the tyre producer, presented with new and difficult problems by the NATO specifications, should not be forgotten. The French concern Kléber-Colombes specially developed the family of *Cross-Country* tyres for these aircraft; their carcass construction and profiles are adapted to the special demands of taxiing over uneven ground. The nearly rectangular section—i.e. gently curved bearing surface—assures maximum response on any terrain, particularly at high taxiing speeds.

In the first tests with low-pressure tyres of this type, a phenomenon known in the trade as "ripple" appeared, i.e. at high speeds the tyre takes the shape of a polygon, and as a result not only is there a worsening of the running characteristics but, even more important, there is a danger of blowout. This phenomenon is caused by stationary waves which arise from periodic local distortion, the internal absorption no longer sufficing to maintain a symmetrical stress state. So-called laminar treads, with reinforced outer layers, were successfully used to counteract the stationary waves.

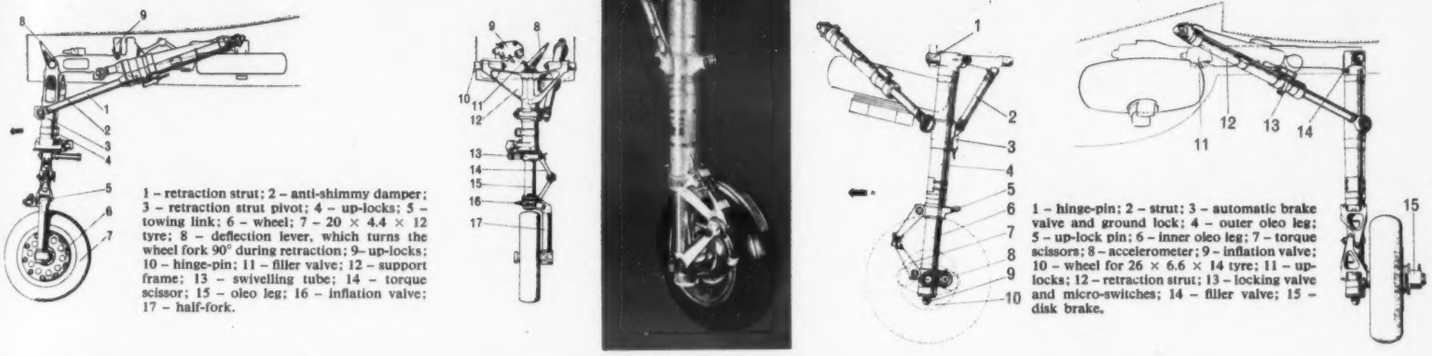
In Italy, Pirelli developed a 9×10 tyre for the Fiat G.91 which, despite its small dimensions (it fits a 10-inch wheel), requires only 50-83 p.s.i. The use of such small tyres created difficulties in brake design, since high stresses have to be reckoned with, especially in the 2-seat trainer version of the aircraft. In order to shield the rims from friction heat, special precautions were required.

Stage 3: The supersonic multi-purpose combat aircraft

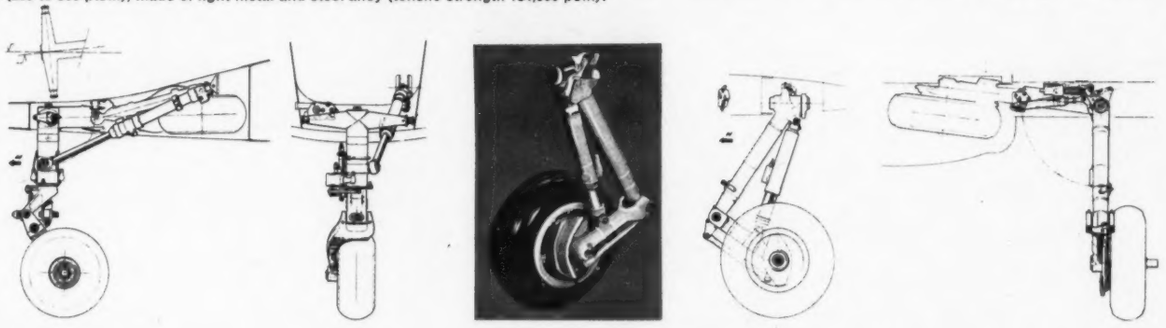
After the NATO competition had proved that high performance was compatible with suitability to operate from makeshift airfields, the French decided to experiment systematically with landings on various terrains to find out the minimum requirements for such aircraft as regards quality of runway. To start with the most unfavourable circumstances possible, tests began on an *Etendard IV,* whose main undercarriage has straight oleo legs and is therefore less suitable for rough terrain than the trailing arm type. First, the longitudinal section of the landing strips from which the tests were to be made (Villaroche, Mont-de-Marsan, Cognac, Toulouse, Brétigny) was plotted, to obtain a basis for objective comparison.

Brétigny is one of the smoother test airfields. The unevenness of the emergency run-

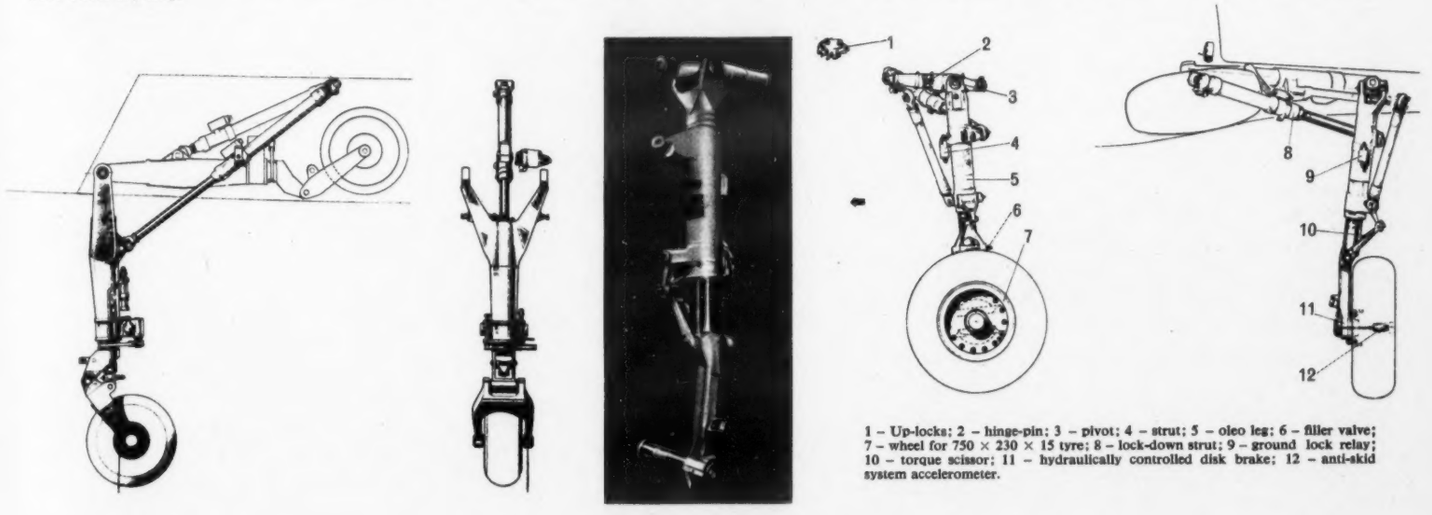
Nosewheel **Mainwheel**


1 – retraction strut; 2 – anti-shimmy damper; 3 – retraction strut pivot; 4 – up-locks; 5 – towing link; 6 – wheel; 7 – 20 × 4.4 × 12 tyre; 8 – deflection lever, which turns the wheel fork 90° during retraction; 9– up-locks; 10 – hinge-pin; 11 – filler valve; 12 – support frame; 13 – swivelling tube; 14 – torque scissor; 15 – oleo leg; 16 – inflation valve; 17 – half-fork.
1 – hinge-pin; 2 – strut; 3 – automatic brake valve and ground lock; 4 – outer oleo leg; 5 – up-lock pin; 6 – inner oleo leg; 7 – torque scissors; 8 – accelerometer; 9 – inflation valve; 10 – wheel for 26 × 6.6 × 14 tyre; 11 – up-locks; 12 – retraction strut; 13 – locking valve and micro-switches; 14 – filler valve; 15 – disk brake.

The revolutionizing of military concepts is reflected in undercarriage construction. Here are three typical examples of nosewheel and main undercarriages.
I – The Dassault SM-B2 *Super Mystère* heavy supersonic interceptor requires weight- and space-saving construction of the undercarriage: conventional oleo legs, small wheels, high-pressure tyres (266 to 300 p.s.i.), made of light metal and steel alloy (tensile strength 184,900 ps.i.).



II – Fiat G.91 lightweight strike fighter: independent of reinforced runways, operates from makeshift airfields, hence fitted with trailing wheels, low-pressure tyres (main wheels 58 p.s.i., nose wheel 50 p.s.i.).


1 – Up-locks; 2 – hinge-pin; 3 – pivot; 4 – strut; 5 – oleo leg; 6 – filler valve; 7 – wheel for 750 × 230 × 15 tyre; 8 – lock-down strut; 9 – ground lock relay; 10 – torque scissor; 11 – hydraulically controlled disk brake; 12 – anti-skid system accelerometer.

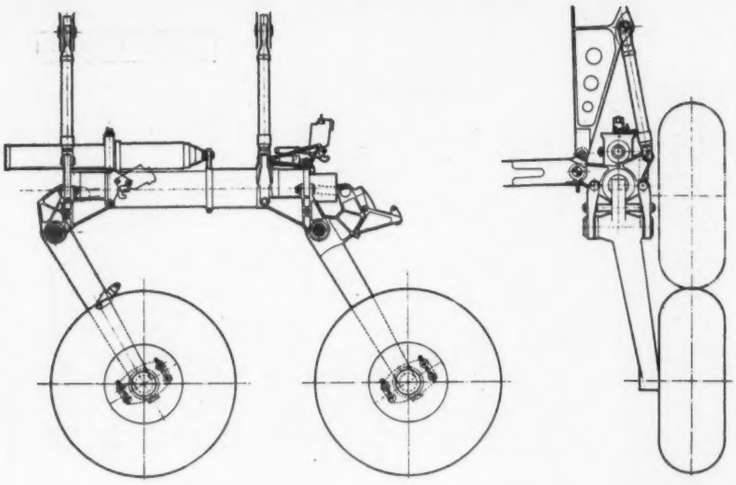
III – GAMD *Mirage IIIC* single-seat multi-purpose combat aircraft: minimum ground support requirements, but high performance (Mach 2+), hence undercarriage weight and space requirements must be kept as low as possible; compromise in the form of medium-pressure tyres (main wheel 117 p.s.i., nose wheel 83 p.s.i.), trailing nose wheel; special retraction owing to thin wing.

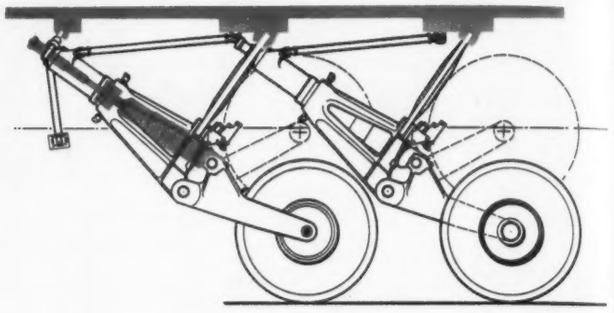
way at Toulouse is shown by the diagram on page 843 and even this does not take account of small humps.

On several occasions during the tests, it proved necessary to modify the shock-absorbing characteristics of the undercarriages to obtain favourable interaction between the wheels and the shock absorbers. The shock absorbers on the main undercarriage have an appreciable effect on aircraft pitching movements during taxiing and thus directly influence the performance of the nosewheel shock absorber. Although during the first tests at Villaroche vertical forces of over 16 tons were recorded even at moderate taxiing speeds, after a few modifications to its undercarriage the aircraft could take off and land on the same runway without vertical forces exceeding nine tons. After take-off, the pilot reported that the "road situation" was perfect.

These tests lasted for some six months, covering winter and spring, and supplied us with valuable information for the development of the undercarriage for the *Mirage III*, an aircraft which despite its high performance (Mach 2+) can operate from makeshift runways.

The nosewheel undercarriage is, of course, of the trailing arm type, with medium-pressure (83 p.s.i.) tyres developed by Kléber-Colom-





For assault transports and other aircraft which must operate from makeshift airfields, Messier has developed the *Jockey* undercarriage. Amazingly simple in construction, it is, in a manner of speaking, the "purest" representative of the trailing arm type of undercarriage. *Above*, a version installed on the Breguet 941. *Left*, the undercarriage for the Franco-German C.160 *Transall*. Tyre pressure in both cases 50 p.s.i.

bes. The structure of the main undercarriage is similar to that of the *Etendard IV*, with a slender half-fork and a 167 p.s.i. tyre. The delta wing demands a special retraction mechanism enabling the wheel to be swung forwards during retraction. As the wing thickness is not adequate for an oblique hinge-pin, we had to use a guide strut. To keep the weight and volume of the undercarriage as low as possible, we use high-alloy steel with a tensile strength of 136,800 p.s.i. for support frame and oleo leg.

Even the first test take-offs and landings on rough terrain proved satisfactory, only a few minor modifications to the hydraulic regulation being necessary. These were due not to the quality of the terrain, but to the delta wing. After nosewheel lift-off during take-offs at high weight, an abnormal compression of the shock absorbers was noted during pitching movements of the aircraft. It was found that this phenomenon was caused by the elevons, which are raised during take-off of a delta-wing aircraft. Inevitably, the air force thus caused acts on the main undercarriage in the case of the *Mirage* and increases the wheel loading. The abnormal compression was eliminated by altering the air pressure regulation of the shock absorbers and hence their dynamic characteristics.

In this way we achieved our aim of creating an undercarriage for high-performance aircraft, an undercarriage which is suitable for take-offs and landings on the steel mesh normally used at front-line airfields—with a margin of unevenness of over two inches.

Transport aircraft

While in the case of combat aircraft rudimentary runways can be provided for take-off and landing, the designer of a tactical transport aircraft must make provision for operations from completely unprepared terrain. Here the theoretical unevenness is of the order of four to six inches. On the basis of our encouraging experiences with trailing arm undercarriages, we decided to choose this type for both the nosewheel and main undercarriages of transport aircraft, particularly as it is ideally suitable for high-wing aircraft in which the undercarriage retracts into the fuselage. The result of our studies is the *Jockey* undercarriage with four wheels retracting into the fuselage. Each undercarriage unit consists of a horizontal support and two trailing arms. The tubular support can be easily attached to the fuselage, usually at the level of the freight hold or cabin floor, and contains a shock absorber with elastic couplings for the two trailing arms. This is an extremely simple construction which offers a number of possibilities for variations, for the trailing arm enables the aircraft to ride smoothly over any irregularities in the terrain. In addition, the tandem wheel layout gives the aircraft good taxiing qualities, and the coupling of the two wheels to a common shock absorber enables the shock forces encountered while taxiing over bumps and hollows to be balanced out in the undercarriage rather than in the fuselage.

Among the particular advantages of the *Jockey* undercarriage is the fact that loading of the aircraft is considerably simplified. By semi-retraction of the wheels, the fuselage can be either lowered parallel with the ground or tilted forwards or backwards according to requirements.

Last but not least, the *Jockey* undercarriage protects the fuselage from heavy loadings—always a delicate problem in the case of pressurized cabins.

The *Jockey* undercarriage was used for the first time in the Breguet 941, whose prototype was recently completed, and will be installed in a slightly modified form in the *Transall* assault transport. To meet the higher weight requirements of this aircraft, each main undercarriage unit has four wheels (tyre pressure 50 p.s.i.), mounted in pairs on trailing arms. The structure and retraction mechanism of both versions can be seen from the illustrations.

Both the 941 and the *Transall* will have to operate from a variety of different terrains—grass, gravel, dust—whose condition changes with the climate: mud, water, ice, snow. To ensure effective braking under any circumstances, an anti-skid system is naturally indispensable. In our opinion, no effort should be spared to bring about substantial improvements in such systems by the use of modern regulation techniques and electronics.

To obtain a clear idea of the stresses to which the undercarriage will be subjected in varying types of terrain, extensive tests were made with a *Noratlas*. A few figures will give an idea of the scope of these tests: 45 measurement points on the aircraft; six months' trial landings on 13 different strips; recording tapes with a total length of 5,000 ft; a further six months spent in evaluating recorded data, during which the readings taken at intervals

of $^1/_{50}$ second were transferred to 200,000 punched cards. Even before the trials began, six weeks of static tests were carried out, enabling the dynamic effects to be clearly distinguished from the basic stresses at a later date.

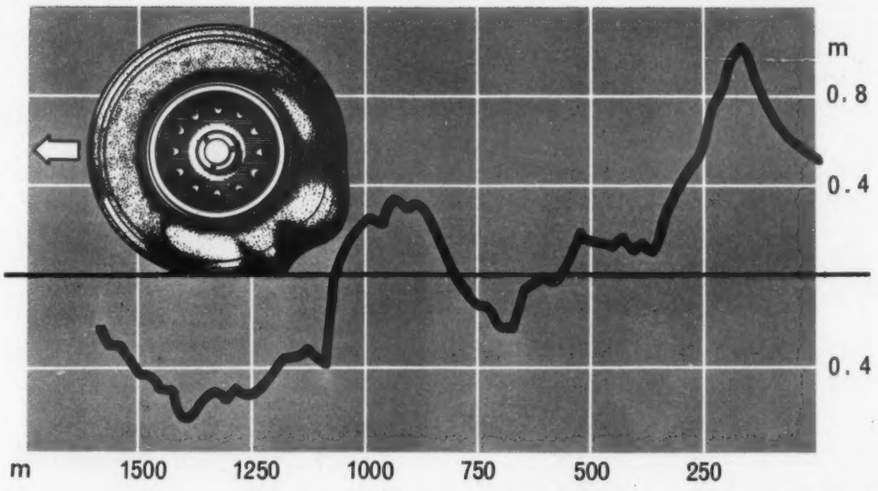
The expense was well worth it, for today we have a comprehensive knowledge of all the main conditions of operation and know what aircraft types can operate from different terrains.

VTOL aircraft

Finally, mention should be made of certain problems which have to be faced in the design of undercarriages for V/STOL aircraft. As developments in this field are still under way, we shall limit ourselves to a few general remarks.

One of the main problems is the heat to which the undercarriages of certain VTOL aircraft are exposed in hovering flight. In most cases the wheels are near the hot jet blast of the lift engines, and in every case they are exposed to the jet exhaust returned from the ground. A variety of promising solutions have been found. Tyre manufacturers are developing materials to withstand temperatures of over 250 °C. An attempt might also be made to protect undercarriages by the doors of the bays into which they retract or by special deflector plates. The way in which the undercarriage is mounted on the aircraft also plays an important part, a circumstance which in our opinion is at present neglected.

The dynamic characteristics of VTOL take-offs and landings are considerably more marked than those of conventional aircraft.



Earlier versions of many low-pressure tyres underwent a characteristic distortion, known as "ripple," during fast roll over rough terrain. This caused the tyre to lose its roundness, thus impairing the taxiing performance of the aircraft and generating excessive heat. The curve shows a longitudinal section through a typical emergency runway, here Toulouse-Blagnac.

On the one hand, undercarriages must be suitable for conventional high-speed take-offs and landings and must therefore withstand powerful horizontal forces (to accelerate the wheels on touchdown and to slow them down during braking); on the other, considerable vertical forces are to be expected during vertical landing, either because the pilot touches down at a high rate of descent, or because one or more engines fail during the critical take-off or landing phase. In the latter case the undercarriage must give the airframe maximum protection against undue stress.

This requires shock absorbers with a very long stroke; here the freely moving spring system gains in interest as certain parts can be designed to bend under the high additional stress generated in an emergency.

In France, the *Coléoptère* was the first full VTOL vehicle; all-up weight 5,940 lb, engine thrust within the ground effect 8,140 lb, four non-retractable undercarriage units, solid rubber tyres and standard production wheels, whose frequent replacement did not involve excessive expense. For an experimental vehicle this solution was highly favourable, as the main objective was to investigate heat effects.

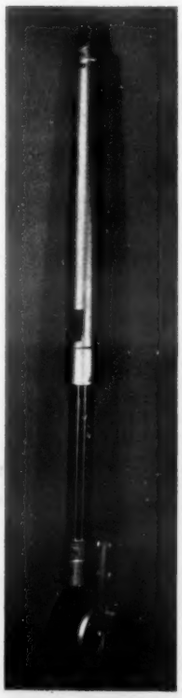
The stroke of the shock absorbers was 26 inches, under a static load of 1,540 lb, i.e., 59 lb per inch. Comparable values for the *Mirage III* are 72 in. stroke under a static load which is often more than 11,000 lb, i.e., over 150 lb per inch.

The *Coléoptère* was, however, little more than a flying test bed, and the development of operational VTOL aircraft will provide undercarriage designers with many a tough nut to crack.

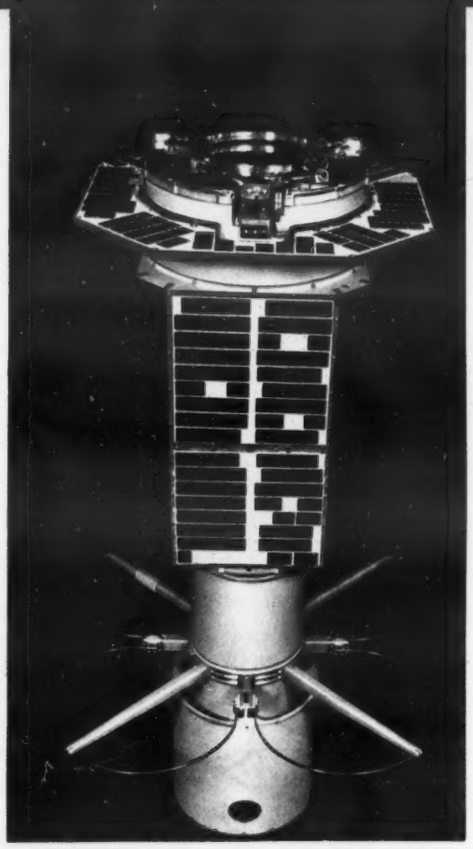
*

In retrospect, it can be said that aircraft development has been marked by increasingly severe take-off and landing conditions. Today, the undercarriage designer can no longer restrict himself to static and conventional dynamic tests, but must get to grips with distortions, fatigue phenomena and vibrations. This obliges him to tackle his problems from another angle. Calculations are still necessary, but experimentation, whether in the laboratory, the technical institute or aboard the aircraft itself, is coming increasingly to the fore.

Aircraft construction techniques are undergoing a development which is typical of the present age. Fewer and fewer problems can be solved singly, for any modification to the smallest detail has far-reaching effects on the whole. →→



Greater vertical landing shocks are to be expected in VTOL aircraft than in conventional ones. This requires long-stroke oleo legs. Picture shows the SNECMA *Coléoptère* experimental vehicle, and the detail the undercarriage leg developed by Messier.



Explorer 11 research satellite. Different in shape from all earth satellites so far launched, it measures 86 in. in length together with the burnt-out fourth stage of the booster (not illustrated), and weighs 95 lb.

When in orbit, *Explorer 11* will tumble end over end ten times per minute, enabling the gamma-ray telescope to pick up rays from all directions. The small disk shown leaving the top of the payload protects the telescope from meteorites, and is ejected by radio command near the end of the satellite's useful life. The two rays projecting from the end of the satellite in the foreground represent the line of sight of the sun and earth sensors, which enable the orientation of the satellite and hence the origin of the recorded gamma rays to be monitored from the earth.

Rockets, Missiles and Space Vehicles

Explorer 11 Research Satellite

American scientists launched the *Explorer 11* gamma-ray research satellite (NASA experiment S-15) on April 27th. A four-stage *Juno 2* boosted it from Cape Canaveral into an orbit with a perigee of 300 miles and an apogee of 750 miles. The orbital period is about 98 minutes, the angle of trajectory 28°. The greater part of the orbit lies below the inner Van Allen radiation belt. The estimated life of *Explorer 11* is over three years, though its useful life is expected to be some six months.

Explorer 11 is the first satellite designed to determine the origin and distribution of high-energy gamma rays in space. This is not possible from the earth owing to interference from existing radiation in the atmosphere. As gamma rays are not deflected by magnetic fields, their source in space can be determined by the direction from which they come.

The tests are being conducted by Drs. William Kraushaar and George Clark of the Massachusetts Institute of Technology, which designed and built the gamma-ray telescope. The Marshall Space Flight Center was responsible for the satellite case and the electronic equipment, and the Goddard Space Flight Center for the scientific management. The booster was supplied and launched by the Marshall Center. The first stage was a modified *Jupiter;* the other stages were powered by Jet Propulsion Laboratory solid-propellant rocket motors.

Data are being sent back to earth by a 125 milliwatt transmitter operating on a frequency of 107.97 Mc/s. For tracking, *Explorer 11* carries a 20-25 milliwatt transmitter, with the entire satellite serving as an antenna; frequency 108.06 Mc/s. A network of doppler stations, some of which have portable equipment, reported the first track data to the Marshall Center. The Goddard Center is responsible for further tracking by Minitrack stations in Woomera, Australia; Johannesburg, South Africa; Santiago and Antofagasta, Chile; Lima, Peru; Quito, Ecuador; Antigua, British West Indies; San Diego, California; Fort Myers, Florida; and Blossom Point, Maryland. The data recorded by the Minitrack stations are first being sent to the Goddard Center and then to MIT for evaluation.

Hydra 2

The U.S. Navy launched a 10 ton, 40 ft powered mock-up of a *Hydra 2* rocket in April. This was floated vertically in the water and launched by the landing craft USS *Alamo* from a point near the island of Santa Cruz, off the California coast. It fell into the Pacific after a short flight and was recovered. This test confirms the U.S. Navy in its opinion that rockets of almost any weight can be launched from the water, thereby enabling complicated launching pads and gantries to be dispensed with. The practical applications of this method of launching will now be investigated.

American Booster Rockets

Booster	Stage	Propellant	Thrust[1] (lb)	Max. diam. (ft)	Height[2] (ft)	Typical payload (lb) Earth orbit[3]	Escape[4]	Mars, Venus
Scout	1	Solid propellant	103,000	3.3	65	150	—	—
	2	Solid propellant	62,000					
	3	Solid propellant	13,600					
	4	Solid propellant	2,800					
Juno 2	1	Lox/kerosene	150,000	8.8	77	95[5]	15	
	2	Solid propellant	15,000					
	3	Solid propellant	4,000					
	4	Solid propellant	1,600					
Thor-Delta	1	Lox/kerosene	150,000	8	92	500	60	
	2	WIFNA/UDMH	7,700					
	3	Solid propellant	15,000					
Thor-Agena B	1	Lox/kerosene	165,000	8	86	1,600		
	2	IRFNA/UDMH	15,000					
Atlas-Agena B	1	Lox/kerosene	367,000	10	98		5,000	750
	2	Lox/kerosene	80,000					
	3	IRFNA/UDMH	15,000					
Atlas-Centaur	1	Lox/kerosene	367,000	10	105	8,500	2,500	1,500
	2	Lox/kerosene	80,000					
	3	Lox/liquid hydrogen	30,000					
Saturn C-1	1	Lox/kerosene	1,500,000	21.6	150	19,000	5,000	2,500
	2	Lox/liquid hydrogen	90,000					
	3	Lox/liquid hydrogen	35,000					

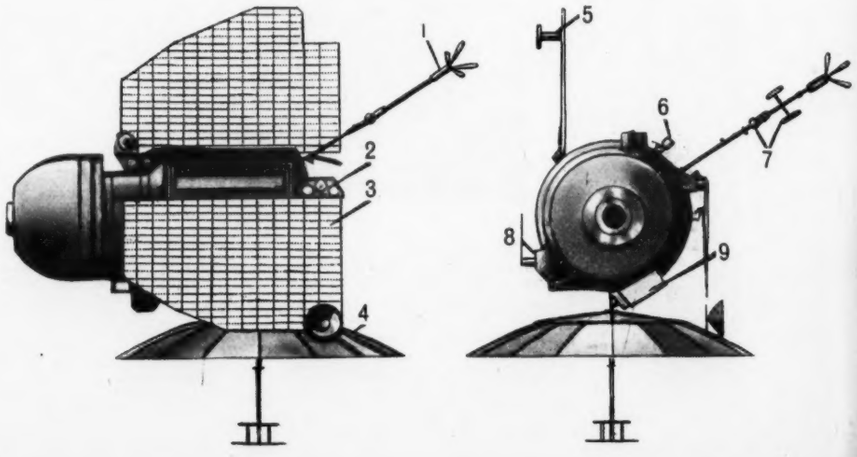
[1]) Thrust of first stage at sea level;
[2]) without payload;
[3]) average altitude 300 n.m., launched eastwards from Cape Canaveral;
[4]) launched eastwards from Cape Canaveral;
[5]) maximum payload.

Venus Probe

Two-view drawing of the Soviet cosmic vehicle.

1 – rod antenna;
2 – temperature control relays;
3 – solar cells;
4 – parabolic antenna;
5 – cruciform antenna;
6 – ion trap;
7 – magnetometer relay;
8 – relays for precise orientation to sun and stars;
9 – relay for orientation to earth.
Dimensions: length 6.73 ft; diameter 3.46 ft.

Although on February 27th contact was lost with the Venus probe launched two weeks previously (cf. *Interavia* No. 3/1961, page 272), Soviet scientists hope that it will be re-established. The probe was said to have come within 60,000 miles of Venus by mid-May, its distance from the earth at that time being some 43 million miles.



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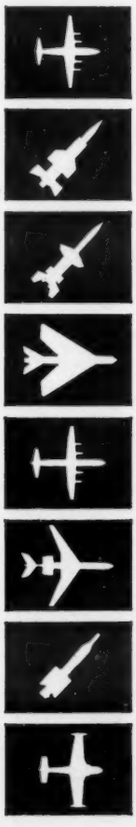


VISCOUNT
VANGUARD
VC 10
BAC 107
SUPERSONIC AIRLINER PROJECT
T-188
CANBERRA
LIGHTNING
TSR-2
JET PROVOST
BLOODHOUND
THUNDERBIRD
VIGILANT
BLUE WATER

BRITISH AIRCRAFT CORPORATION

ONE HUNDRED PALL MALL LONDON SW1 ENGLAND

BAC 21

BEGINNING OF THE

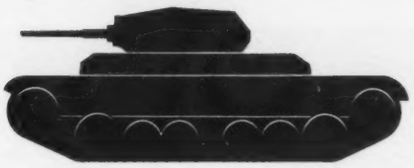
■ The target for this Vigilant round may be hull down and a mile away—or it may be only just out of the picture.

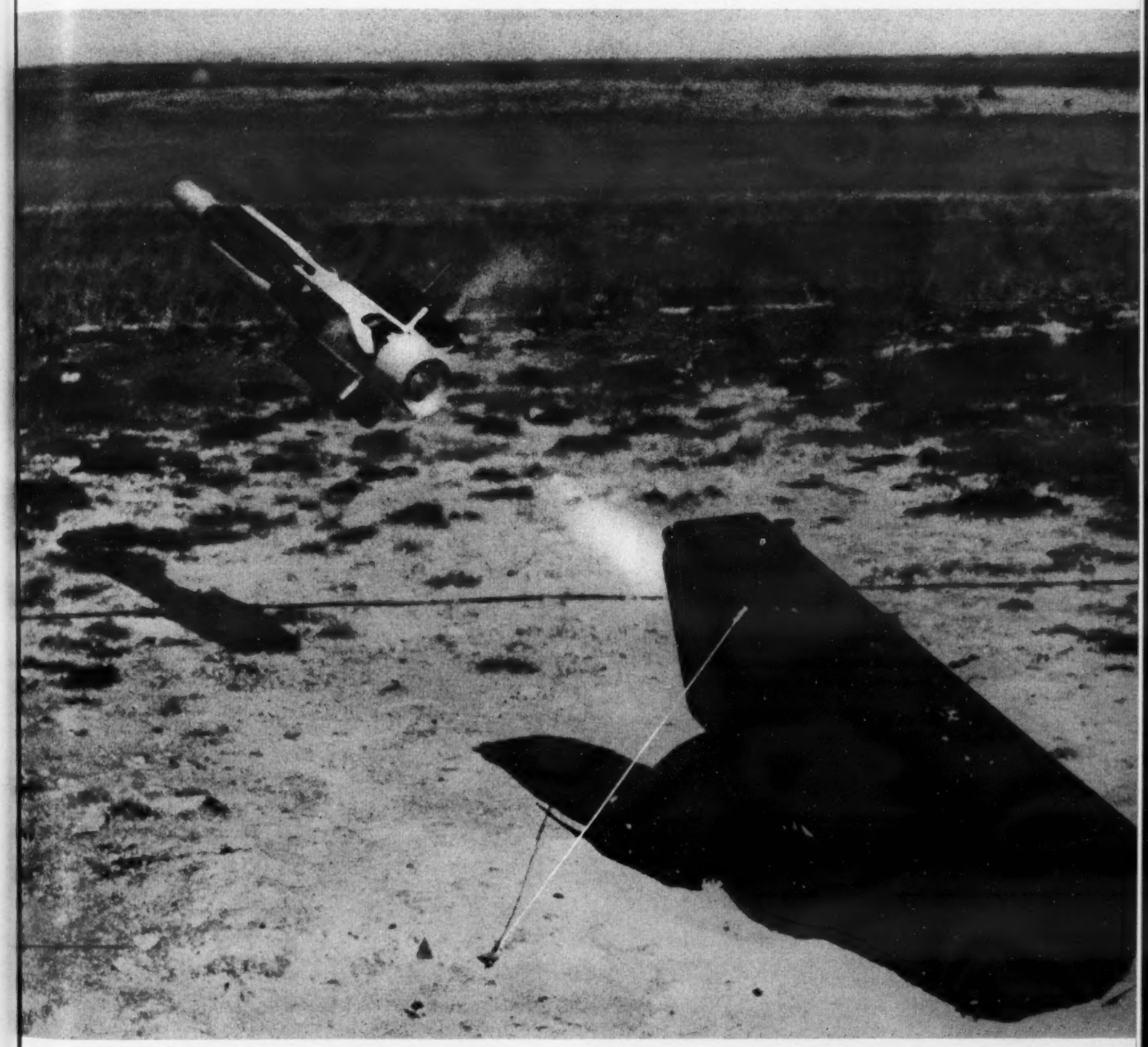
■ In either case the tank will never know what hit it.

■ It will have been knocked out easily, smoothly and surely, by one man — himself hidden, and secure in the knowledge that no flash or smoke from Vigilant has betrayed his position.

VICKERS **VIGILANT**

END OF A TANK





one-man anti-tank weapon

VICKERS-ARMSTRONGS (AIRCRAFT) LTD. WEYBRIDGE SURREY A Company of

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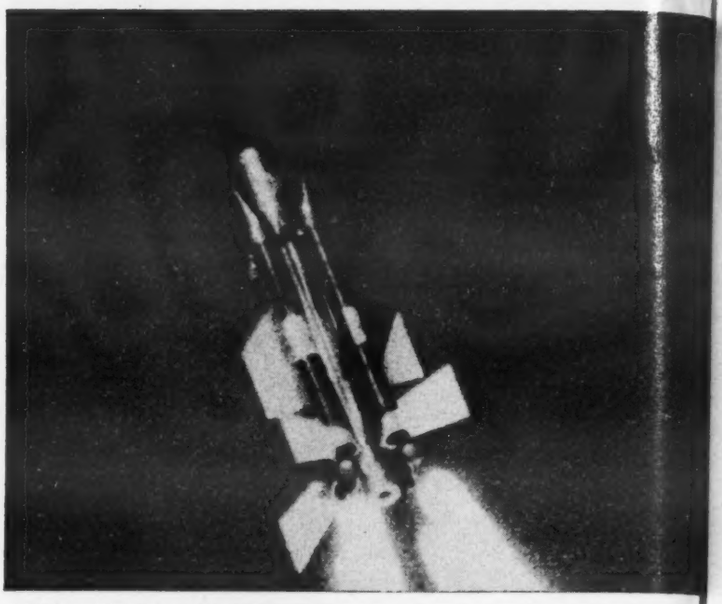
ONE HUNDRED PALL MALL LONDON SW1

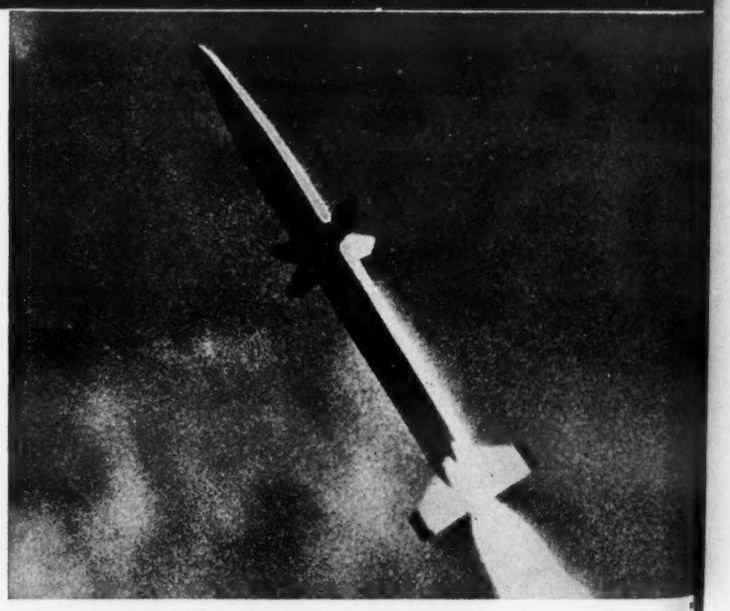
VICKERS **VIGILANT** The Anti-tank weapon which gives the infantryman and the paratrooper the ability to kill the heaviest tank. The *Vigilant*'s auto-pilot ensures the accuracy and ease of control from which stem the highest efficiency and lowest training costs.



'ENGLISH ELECTRIC' **THUNDERBIRD** A fully mobile, solid-fuel, air-transportable ground-to-air missile in service with the British Army. A development contract has been placed for Thunderbird Mark II.

4 GUIDED MISSILES FOR WESTERN DEFENCE

BRISTOL/FERRANTI **BLOODHOUND** A long-range, high-altitude, ram-jet powered, ground-to-air missile adopted by the Royal Air Force, Sweden & Australia. Bloodhound Mark II is now under full development.



'ENGLISH ELECTRIC' **BLUE WATER** This tactical surface-to-surface weapon is Britain's second-generation army missile. It has a solid-fuel motor, inertial guidance, high accuracy, rapid fire power and great mobility.

AND BUILT BY

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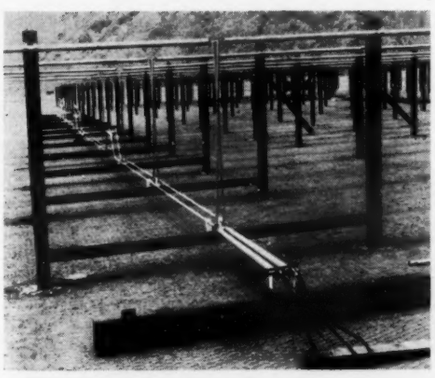
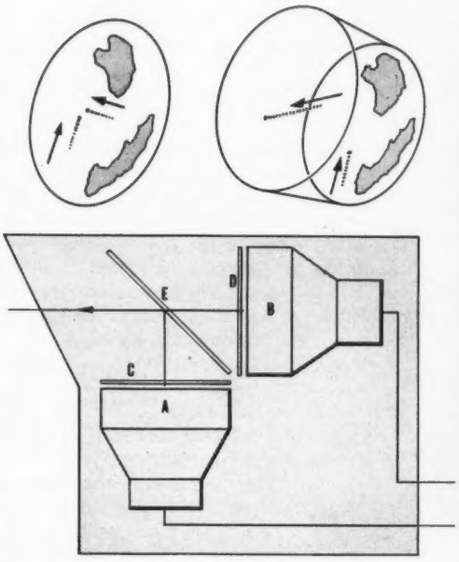
ONE HUNDRED PALL MALL LONDON SW1

Research and Production News

■ At **Jicamarca Observatory**, in Peru, 17 miles east of Lima, near the magnetic equator of the earth, scientists of the Instituto Geofísico de Huancayo and the U.S. National Bureau of Standards are jointly studying the upper atmosphere. For this purpose a giant radar has been built, consisting of a total 9,216 separate crossed-dipole elements (see picture); covering an area 1,000 ft square, it has ten times the collecting surface of the radio telescope at Jodrell Bank, England. Research work at reduced transmission power began on May 15th this year. By December, however, the full power output of 6 MW will be available, enabling very high frequency waves with a duration of 50 to 1,500 microseconds to be radiated into space. The highly sensitive antenna then picks up the faint echoes from free electrons in the upper atmosphere. The purpose of the operation, which uses a new radar method developed by Dr. K. L. Bowles of the National Bureau of Standards, is to investigate the following properties of the earth's atmosphere at altitudes of up to 2,000 miles: chemical composition of the ionosphere, electron density, kinetic temperature of the ions, percentage composition of the major ionic components, intensity of the earth's magnetic field, echoes from solar gas clouds, small-scale irregularities in the outer atmosphere. It is also intended to investigate turbulence and meteorological phenomena in the D-layer (the lowest layer of the ionosphere), and to calibrate earth satellite instrumentation by comparing the levels indicated by its measuring equipment with those derived by the radar. The new installation will also be able to detect radio stars one order of magnitude fainter than those observed to date.





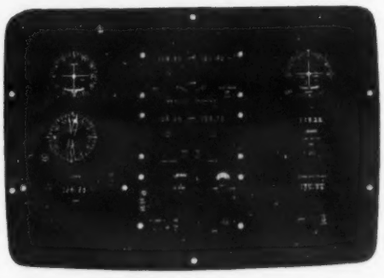
■ **Hughes Aircraft Company, Culver City, Calif.**, has demonstrated a new display for the stereoscopic presentation of radar data, offering wide possibilities for air traffic control and airspace surveillance. Whereas two separate screens were previously required to display aircraft range, azimuth and height, the new system offers three-dimensional display of aircraft echoes in the airspace. Named *Stereoscan* by the manufacturer, the equipment consists of two 21 in. Hughes *Tonotron* direct view storage display tubes mounted at right angles to each other (A and B), in front of which are two polaroid filters (C and D). A half-silvered mirror (E), set at an angle of 45° to the plane of the surface of each tube, causes the faces of both tubes to appear to coincide with one another when viewed by the observer, who wears polaroid spectacles (to correspond with filters C and D); the information displayed on tube A is thus seen only with the left eye, while that displayed on tube B is seen only with the right. By the use of an additional time-varying voltage proportional to the sine of the antenna angle of elevation, which is added to the saw-tooth deflection voltage of one display and subtracted from that of the other, a parallax displacement of the echoes on both screens is achieved. As the screens are viewed separately by the left or right eye, the impression of a three-dimensional presentation is given.

According to first reports, the *Stereoscan* presentation offers some important advantages: it is more easily and accurately read than conventional screens, and it is not necessary to darken the room. The price of the display is relatively low, as most of the components used are already in production for other equipment. Particularly important is the fact that existing 3D radars can be used for *Stereoscan* presentation without modification. Finally, the use of *Tonotron* tubes means that the aircraft flight paths are visible for some time; this considerably improves clarity of presentation, even in zones of high traffic density.

Hughes Aircraft Company, which has for some years been producing 3D radar systems, used a *Frescan* electronic-scanning radar (see picture) to demonstrate the display; the *Frescan* is to be installed on the U.S. Navy's new guided missile cruisers and destroyers. A similar equipment, the *Frescanar*, is already in operation with the U.S. Army in Europe as a fire direction system.

■ **The Canadian Marconi Company, Montreal,** offers a light, compact, two-way, short-range radio unit, which because of its small dimensions is particularly suitable for installation in vehicles, cranes etc. The equipment, which conforms to Department of Transport standards, was developed specially to meet growing industrial requirements. It is unaffected by vibrations, shocks and even dripping liquids, is fully self-contained and has excellent performance with low power output and high receiver sensitivity.

■ **The Sperry Gyroscope Company, Great Neck, New York,** uses spherical aluminium reflectors six inches in diameter to check the performance of the radars which it has developed for missile guidance, air defence and air traffic control. The low-cost reflectors are attached to balloons which travel hundreds of miles. After a balloon is launched, the radar is first manually turned in the direction of the target. As soon as the radar detects the reflector, it automatically locks onto it and continues to track its further movements. Despite the relatively small dimensions of the spheres, they have often been followed out to surprisingly long distances. If a radar has proved its performance under a test of such severity, the manufacturer can guarantee that it will have the required accuracy and reliability under normal operating conditions.



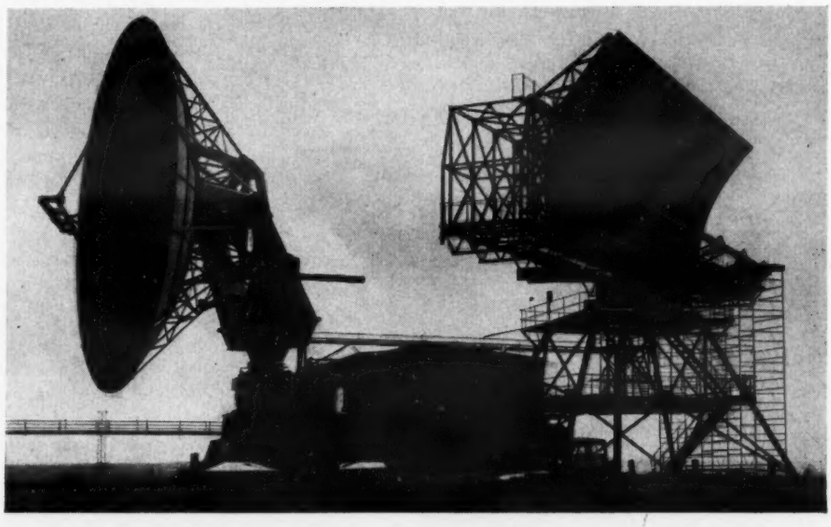
■ **Dare, Inc., Troy, Ohio,** has recently introduced its current range of radio and navigation equipment to Europe. At the upper left are the visual indicators of the DM-3 transistorized Marker Beacon receiver. Below the lamps is the DNI-2 navigation indicator combining the omni bearing selector, flight path deviation needles for glide slope, omni and localizer functions, to/from indicator, and flag alarms. The lower dial is the DNI-4 dual indicator for the ADF. Bottom left is the control head for the DGS-20 twenty-channel glide slope receiver, operating from a transistor power supply.

The navigation indicator and control head for the DR-480 VHF receiver are at the upper right of the panel. This is a completely transistorized receiver providing 480 channels in the 108-131.95 Mc/s band. The combined weight of the two units is less than 5 lb; no power pack is required, as the installations can be operated from dry cell batteries.

The controls for the DTR/360B VHF transceiver are at the upper centre. This two-way control enables the pilot to preselect the next frequency required, and then to change over by means of the central switch. A second frequency can then be set up on the unused head. The two lower panels are the control heads for the DN-560B navigation/communication system and the C/DADF-1A automatic direction finder.

■ **Westinghouse Electric International Company, New York,** announces the development of a miniature radar display for use in aircraft. With a length of only 8½ in., it weighs 2 ounces and has a picture surface 0.6 in. in diameter. The screen is enlarged ten times by a magnifying glass and has 900 lines (about three times the number on a normal television screen), giving extremely high resolution. The display has highly promising possibilities of application in private aircraft and boats, as its use would greatly reduce the overall costs of a radar equipment and would simplify the space problem. A further advantage of the new display is that the screen can be easily read even in bright daylight.

■ **Marconi's Wireless Telegraph Company Ltd., Chelmsford,** is making intensive studies of active and passive communications satellites. The picture shows the reflector (30 ft in diameter) of the tracking radar and another radar antenna at a Marconi research station, where experiments are at present being carried out in tracking passive satellites.



Primary Radar in Air Traffic Control

*by A. M. Patrick, A. M. Brit. I.R.E.**

Air Traffic control is on the threshold of important changes because techniques are now available for speeding up the flow of traffic and for the introduction of more flexible procedures, which will permit rational and safer use of airspace. Inevitably, this will lead to changes in present procedures which, in many areas, are subjecting expensive aircraft to delays and thus preventing their proper economic use. By 1965 we shall undoubtedly see radar cover greatly extended and control systems which incorporate a judicious compromise between analogue and digital methods and are well conceived from the human engineering and safety aspects. These will reinforce the present ATC system in those areas where traffic density warrants it. The qualification is important, since neither radar nor modern data-processing methods are likely to be introduced wherever the task can be done by simpler, cheaper means. In this context it is true that there are many areas in the world where traffic densities are low, and where present methods of data-gathering and data-processing are adequate; but with the general increase in traffic these areas are becoming fewer.

The key-word in air traffic control is *control*. The whole process can be regarded as a large servo-loop in which data is gathered, compared with constraints set by international separation standards, and adjustments made to maintain these standards. But this control procedure, like all control procedures, is as good as the quality and rate of the data flow and no better. A simple example is driving a car: in fog, data received by the driver are bad and his control and progress are reduced accordingly; but suppose he is driving in clear conditions with closed eyes and relying entirely on the front passenger for instructions, then, whilst the data may be of good quality, the flow would be slow and there would be considerable loss of efficiency. In other words, both quality and rate of flow must be matched. Good data-processing is of value only with good data, and vice-versa.

Traffic Density

An efficient air traffic control system is one which makes data of sufficient quality available, as and when required, to the indispensable human controller for dealing with a particular air situation. Where traffic density is low, as in many areas, radio beacon reports may supply adequate data. Furthermore, there may be no difficulty in assimilating and selecting the data relevant for control purposes from a simple display of all available data. There may also be time for the controller to monitor potential conflicts and so forth. In other words, the data is easily obtained and easily handled.

However, where traffic densities are higher, the data from beacon reports are by no means adequate. Firstly, the position and velocity data are of poor quality and only available at a low data-rate, involving as a corollary the allocation of a large volume of airspace to each aircraft. Secondly, data are provided only on aircraft inside a small section of the airspace, namely the airways, and no information at all is available on aircraft outside or near the airways. The whole procedure is thoroughly inflexible and grossly inefficient in its use of airspace—penalties which limit both flight profiles and the number of individual air movements, and which are therefore very costly in the overall economic sense.

Furthermore, where densities are high enough to require, say half-a-dozen or more controllers' positions, then the collation of data from multiple sources, the processing, computation and selection for clearances, potential conflicts, etc., and the routing of the relevant selection of data to the right place at the right time—all consume an appreciable portion of each controller's time. In such conditions, the controller spends a significant part of his time on routine, as opposed to specialized, work and to this extent is under-employed as a *controller*.

At this stage—even without considering the use of radar—an operational research study to elicit a quantitative assessment might well suggest mechanizing these purely book-keeping aspects, in order to make the most of the beacon data. With the better quality, more complete and more frequent data supplied by radar, the arguments for this step are considerably reinforced. The radar aspects will be discussed presently; at this juncture it can be pointed out that, once the stage is reached where digital techniques can be economically and usefully employed—and in the current state of the art this applies to smaller densities than many people imagine—, then other advantages can be obtained as a by-product.

DASR-1 radar installation by Decca Radar at Maiquita, Venezuela.

Integration of civil and military navaids

One of these advantages is the integration of military and civil *equipments*, irrespective of whether it is decided to integrate civil and military *control*, the latter decision of course involving strategic, tactical, political and other considerations. However, whether we like it or not, and whether we admit or not, some degree of civil/military integration is inevitable. The reasons for this are that modern navaids and modern radars range over large volumes of airspace; that modern automation techniques offer the potential safe control

* Decca Radar Ltd., London

of aircraft over large volumes of airspace; and that, for economic operations, modern civil aircraft are increasingly demanding volumes of airspace not limited by airways, and encroaching on what has previously been solely military airspace.

The sceptics have so far on the whole held the fort; this in the absence of a comprehensive operational philosophy which might have led to the engineering effort necessary to introduce joint facilities at ATC centres. However, this state of affairs is rapidly changing as a result of the research and of the system studies carried out in Europe and America in recent years. In particular, the recent announcement that the British Government are already making certain military radar installations available to the Civil Aviation Authority for joint air traffic control services above flight level 250 (approx. 25,000 ft) is a significant and practical step towards making the best operational and economic use of extremely efficient and advanced military radar.

The Merits of Radar in an ATC Role

Considering that radar is 20 years old and that it plays a significant and integral part in defence systems, it is rather surprising that there is, up to now, no place in the world where radar is *fully* integrated into the ATC system. The reasons for this have been:—

(a) The non-availability until comparatively recently of suitable and reliable radar equipments. As we shall see later, the air traffic control radar requirement is a very stringent one;

(b) Failure to appreciate the advantages and limitations of radar, such appreciation being essential to ensure its exploitation with confidence and safety in an integrated operational role;

(c) In most places, for most of the time, the delays have been just tolerable.

Of these reasons the third is no longer true, especially over routes with substantial jet traffic, the number of which is of course increasing. The first reason also is no longer valid, since one can now point to a number of radars specially designed to meet the requirements of civil air surveillance which give highly encouraging results. Finally, situation (b) is rapidly changing.

Primary radar is the sole means of obtaining high-accuracy information on all aircraft at a high data-rate throughout large volumes of airspace *without the necessity for active co-operation of the aircraft themselves*. Compared with the reporting beacons, the data accuracy is about 10 times better, the data are acquired on *all* aircraft instead of only those under control, the data-rate is about 100 times more frequent, and the volume of airspace includes a substantial volume of the flight information regions (FIRs). This combination of advantages is unique to primary radar, and much greater flexibility and efficacy of control is potentially possible for these reasons:—

— A picture of the air situation is available which can be more readily assimilated than numerical data from flight progress strips.

— R/T bandwidth is not taken up in establishing the picture and is more available for control purposes.

— Advantage can be taken of the accurate relative positions which radar provides.

— Modern radars are highly reliable in themselves as compared to earlier equipment. Duplication of key units and application of fail-safe limits in design are now common practice.

Other data-sources are beacons and navaids of differing accuracies and coverage, which overlap and supply a useful element of redundancy without duplication. A well-designed data-processing system, using modern computer techniques, makes possible flexible control procedures which can be adapted to take advantage of the quality of data feeding the ATC system at any given time. In this way the latest systems, far from depending solely on any one data source, take advantage of all available navaid data to improve control and rationalize the use of airspace.

Radar Design Problems

There are many problems in radar design. Conflicts which can only be settled by compromise arise in the choice of parameters by reason of their basic relationship to each other as defined by the radar range equation. This situation applies in general regardless of the role, be it long-range (en route), airport surveillance, precision approach, or ASMI, although radar equipments for each of these naturally vary greatly in detail. What follows is confined to the surveillance case.

An air surveillance radar for ATC must give cover with the greatest possible freedom from gaps and at a high data rate. It must have high resolution, especially in azimuth, and have effective ground and weather clutter suppression capabilities. It must also be capable of being easily sited, seeing that at many airports there are severe limitations in respect of available positions. These characteristics are considered in further detail below.

Solid cover. The theoretical coverage diagram for a radar is drawn for 'free space' conditions; but in practice, due to reflection of the indirect rays striking the ground, its smooth contour is greatly altered. The ground reflections interfere with the direct ray, causing the free space pattern to break into a series of lobes which give unacceptable gaps in the coverage. A number of factors influence the number, spacing, and amplitude of the lobes, most important being wavelength. The shorter the wavelength, the finer the lobing pattern, and consequently the nearer the coverage to being gap-free.

Data rate. Renewal of information at a rate of ten times a minute is generally considered a minimum rate for present and future ATC use if good tracking of high-speed aircraft is to be maintained (an aircraft flying at 300 miles per hour covers 5 miles in one minute.) In practice, it is easier to rotate a small aerial accurately than a large one. Here again, wavelength is important, because the longer the wavelength the wider the horizontal aperture required for a given horizontal beamwidth. Data rate is also related to maximum range because a high data rate aerial illuminates the target for a shorter time than a low data rate system, thus reducing the total energy received at a given point and consequently affecting the maximum range of the radar.

Resolution. A high power of range resolution is inherent to radar. Azimuth resolution is of even greater importance in ATC, and horizontal beamwidth is the governing factor. Obviously, the narrower the beamwidth the better the resolution because, as the cross section of the beam increases with distance from the aerial, resolving power falls off. Once again wavelength is significant owing to the relationship between aperture beamwidth and wavelength described above.

Clutter. Returns from buildings, mountains, and other obstacles produce strong echoes which can obscure those from over-flying aircraft, particularly at the shorter ranges. Reflections from rain and snow may produce similar effects at all ranges, and with increasing wavelength the strength decreases.

Siting. This depends on many considerations, including the nature of the terrain, reflection co-efficient and wavelength. Here again, shorter wavelength systems provide more constant coverage owing to the limiting lobing to which they are susceptible.

When these interdependent factors are faced in detail, it is clear that the fundamental choice lies between the S-band (10 cm) and the L-band (23, 25 or 50 cm) as the operating wavelength.

To achieve the same azimuth resolution and accuracy, an L-band radar requires an aerial several times larger than an S-band system. The problems of designing such a structure and its associated turning gear so as to withstand wind pressure without loss of precision, and to rotate at not less than 10 r.p.m., are commensurately more difficult and costly. Moreover, the lobing effects present a very serious obstacle to obtaining anything approaching solid cover, and complicate the task of finding a suitable site—a seemingly straightforward

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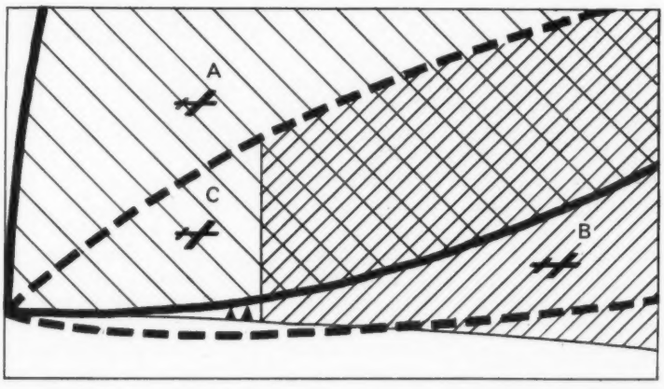
consideration, but one which frequently presents almost insurmountable difficulties, particularly at large airports.

In every one of these important respects an S-band radar is superior. A compact aerial, rotatable at high speeds, can be easily achieved. Such a radar can be sited in a greater variety of situations, since it is virtually independent of the lobing problem. Solid cover is much more readily obtained, and can be reliably maintained without unpredictable variation. High resolution is also readily achieved.

On these grounds therefore, one would obviously choose the shorter wavelength. However, it has the inherent disadvantage that reflections from precipitation (rain, hail, snow, etc.) more readily obscure aircraft echoes. Furthermore, the application of MTI techniques to assist in the elimination of ground clutter is more difficult to engineer. It is these disadvantages of weather and ground clutter to which L-band is much more, though not completely, immune, that have hitherto made the choice between the two wavelengths extremely difficult. Many users have accepted the known operational shortcomings of L-band in favour of its clutter advantages while others have decided, after consideration, that S-band characteristics provide on the whole greater potential for efficient ATC surveillance radar.



How the ATI works. The radiation diagram of the two antennas, which are mounted back to back, consists of two separate beams. The upper beam is designed so as to be uninfluenced by ground clutter and detects aircraft at high altitude (A), more distant low-altitude targets (B) being taken care of by the lower beam (shown here by a broken line). The elimination of ground echos, whose interference is particularly marked in the proximity of the antenna itself, is carried out by blanking out the lower beam to the specific distance desired. An aircraft flying low and at a short distance from the radar antenna (C) is then detected only by the upper beam.

Advances in clutter suppression

In recent years two developments have taken place which have made it possible to combine many advantages in a single S-band system and eliminate the disadvantages of S-band vis-à-vis L-band in respect of clutter.

The first of these is the latest development of the circular polarization technique, whereby true circular polarization is achieved. A new polarizer of this type has been developed and fitted in the Decca DASR-1 air surveillance radar, where a suppression performance in heavy precipitation from cumulonimbus clouds of 25 dB is regularly obtained. Not only is this a higher figure than any previously achieved, but also the actual measured difference in signal-to-noise ratio between linear and circular polarization on aircraft echoes is confined to less than 2 dB, as compared with the losses of 3-6 dB which formerly accompanied this technique. Previously a measure of ellipticity where the ratio of major to minor axis is 10:9, i.e. 90% circularity, has been accepted as nominal circular polarization, and even this was not achieved throughout the whole coverage. With the new polarizer, on the other hand, the actual value comes much nearer to 100% circularity throughout the beam, which is one of its most significant features.

The second technique, ATI (air target indication), involves an aerial system of two or more overlapping lobes, the lowest of which is used for providing radar cover on aircraft at ranges beyond the permanent echoes. The illumination it gives to the ground at nearer ranges is reduced by a combination of swept gain, instantaneous automatic gain control (IAGC) and, if necessary, blanking. The illumination of aircraft at altitudes near the ground at near ranges is supplied by the second (upper) beam. This has been possible by modern S-band aerial systems, which have high directivity and consequently low angle cut-off. The judicious surgery of these four elements —swept gain, IAGC, blanking, and low angle cut-off—allows unwanted ground returns to be virtually eliminated. Collectively the system has been called ATI, and it provides a flexible combination for meeting a very wide variety of terrain conditions, thereby facilitating siting.

From what has been said, it is apparent that ATI is an inherent part of the design of the radar itself. In particular, it places no constraints on the choice of parameters, and optimum radar performance is therefore not impaired by its incorporation. Moreover, the system is flexible in that the various special receiver circuits and the angle of the radiated beams can be adjusted, as required, to suit the local conditions of any particular site.

The ATI approach to permanent echo suppression differs basically from the classical MTI technique, which is well known and has given wide and useful service in military and civil radars. In MTI, received signals are operated on by electronic circuits, so as to extract a definite characteristic, namely the phase difference induced by a target's motion in accordance with Doppler principles, which enables a distinction to be made between moving and stationary targets. Fitted by itself, as the only permanent echo suppression device in a surveillance radar sited in mountainous countries, MTI is limited in the relief it can give. Measurement has shown that the strength of the signals which a good MTI can cancel falls far short of that actually returned by large mountains. MTI also imposes certain restrictions in design, especially as regards aerial rotation rate and prf. However, where the radar is designed basically for ATI, a sufficiently good MTI system can still be developed to give added anti-clutter protection and Decca Radar has for example, developed transistorized MTI kit for their DASR-1. This addition of MTI to the inherent ATI suppression system designed into a radar of the DASR-1 type produces a higher overall suppression performance than can be achieved by 100 percent MTI or by ATI alone. The dual system also provides great flexibility from the point of view of setting up the suppression system to perform efficiently at different sites: the MTI component is range gated and employed only where absolutely necessary in the coverage, while the variation of beam angles and receiver characteristics enables the ATI performance to be adjusted for the most efficient performance, having regard to operational demands and site characteristics.

Conclusion

Advantage must be taken of the performance and reliability of radar by incorporating it as an integral part of the ATC systems of the future and there are encouraging indications that this will be done. Already much experimental work has been carried out on semi-automatic traffic control data processing using radar information as one of its primary inputs. Such developments and the wider use of equipment on a joint military/civil basis offer today a tremendous scope for technical and operational advance.

Radar systems with gapless coverage, high definition, and data rate have already been developed, and are capable of providing precise, accurate information over very large volumes of air space. If this source of information is fully exploited, air traffic control will in the future greatly increase its contribution to the safety and profitability of air transport. ◆◆

Electronics

Telemobiloscope to Digital Radar

In the same year as the English physicist J. A. Fleming, for the first time in radio history, used an electron tube for receiving electric waves, the German engineer Christian Hülsmeyer was granted a patent (April 30th 1904) for his "process for reporting distant metallic objects to an observer by means of electric waves." In spite of several successful demonstrations of his "telemobiloscope," Hülsmeyer did not succeed in interesting anyone in his discovery and for the rest of his life (he died in 1957) Hülsmeyer took no further interest in the matter.

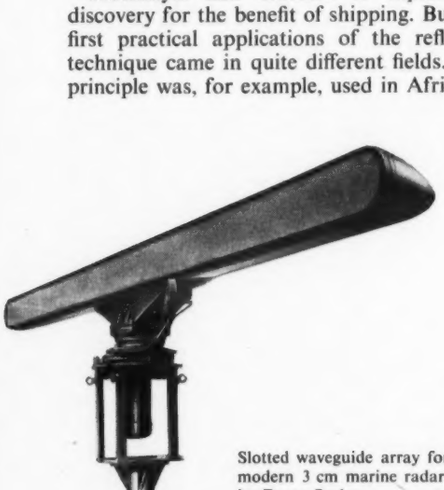
Hülsmeyer had intended to exploit his discovery for the benefit of shipping. But the first practical applications of the reflector technique came in quite different fields. The principle was, for example, used in Africa in the year 1914 to measure the depth of water conducting layers of the earth's crust and in 1926 G. Breit and M. Tuve successfully determined the altitude of the ionosphere from the duration of reflected electric pulses. In aviation the technique of radio ranging was used for the first time in 1931, and in shipping not until five years later.

In radar, as in many other fields, it was military demands which provided the impetus and incentive for meteoric development. During World War II, radio ranging methods were developed out of modest beginnings into systems with no mean performance. But soon after the war, the military planners demanded still higher performance and new applications. Radar antennas shot out of the ground like mushrooms (in England alone there are today over 300 radar installations), and radar came to be used in more and more fields. If, at first, the position and direction of movement of aircraft or ships could be ascertained only very roughly, demands on radar technology continued to grow (higher accuracy, greater range, finer measurements, improved operational safety, and so on).

Radar equipment today fulfils a variety of purposes. Radar makes it possible to watch relatively slow-moving ships and to detect intercontinental missiles travelling at several times the speed of sound; the monitoring of outer space is as much radar's task as the meticulous control of aircraft in bad-weather approach flights; the police use radar for checking the speed of road vehicles and in radio astronomy radio techniques assist in bridging unimaginable distances; if the radar in commercial aircraft serves such peaceful purposes as navigation and warning the pilot of bad weather zones, it also plays its part in making combat aircraft extremely dangerous weapons of attack.

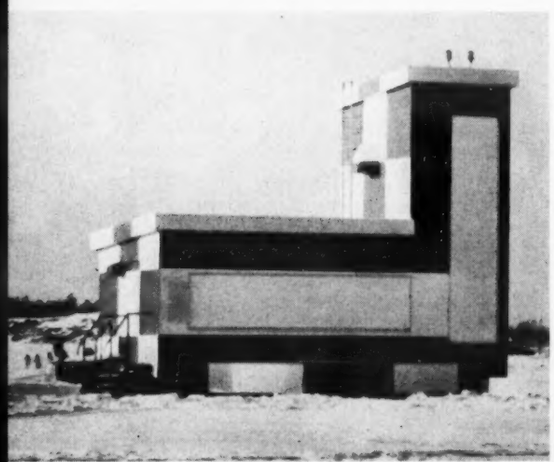
In the civil aircraft sector, military radar developments have for a long time dominated the scene. Until a short time ago, practically the only equipment available for flight safety duties was equipment originally designed for military purposes and at best modified—and generally not completely so—to suit the new requirements. Today however, many con-

Antenna of the FIAR P33 airport surveillance radar.

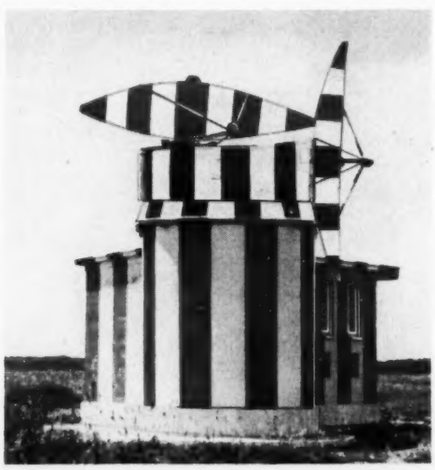


Slotted waveguide array for modern 3 cm marine radar, by Decca Radar.

SLA.3 precision approach radar by Standard Telephones and Cables.



Telefunken's PAR-2 precision approach radar is slewable in six different approach directions by remote control.



Selenia's *Meteor 200* type RMC-1c weather radar for automatic tracking of weather balloons and for storm warning.

The control centre at Bordeaux-Mérignac was recently equipped with a Thomson-Houston (CFTH) TH.D.225 air traffic control radar.

cerns offer radar systems, which are specially designed for the requirements of civil ATC and may also satisfy future air traffic control requirements. At the same time as the new radar systems, advanced systems for the transmission, presentation and processing of radar data as well as considerably stronger transmission tubes, parametric amplifiers and modern echo suppression systems have been developed. In short, the problem of creating efficient equipment has been tackled from all sides.

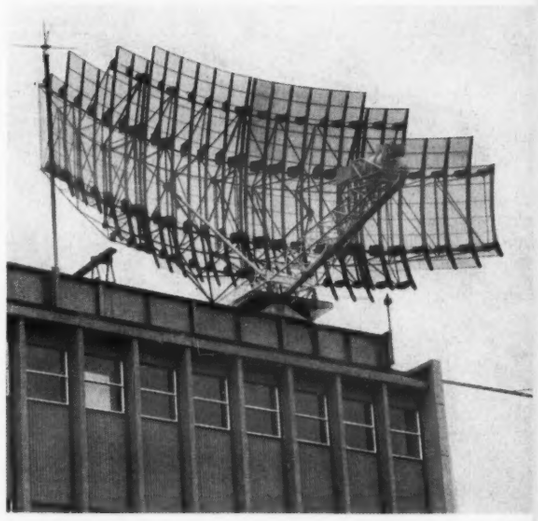
The fact that in part the new systems differ considerably from each other—for example in the frequencies utilised—is of secondary importance as far as their individual performance characteristics are concerned, since the manufacturers endeavour to offset the disadvantages attached to every method by additional facilities or devices, so that the choice of a radar system is influenced more by financial or political than by technical considerations. In other respects however—and this is of particular importance for civil aviation—an internationally uniform procedure should be found as soon as possible. In this connection, it is enough to stress the necessity of integrated civil/military radar control—encouraging starts have recently been made in Great Britain—and the problem of sidelobe suppression and data transmission in secondary radar.

In shipping, development has been somewhat more conservative. Apart from the fact that a number of different types of highly specialised equipment are in use in warships and for coastal defence, more and more ships of merchant marines, even trawlers and coasters, are equipped with their own radar. For simplifying navigation in narrow waters, river mouths and ports, land stations are coming into operation in growing numbers. Since the demands on a non-military ship's radar are far less exacting than on radar equipment for military purposes or for air traffic control, one should also be able to count on the development of this type of radar continuing fairly smoothly in the future.

This is certainly not true of space travel, air defence, weapons guidance systems and air safety radar control. In these fields, one can expect the turbulent development to continue. Advanced presentation systems for existing radar systems should be operational before long. Daylight screens are already starting to find their way into operations rooms. Work is going on at high pressure on three-dimensional indicators; colour-television presentation of the radar image is under development and a short time ago there was talk of a new process which makes use of the Piezo-electric effect and electroluminescence to produce a light image on an extremely flat screen, which could perhaps one day replace the cathode ray tube.

The radar systems themselves are also making continuous progress. New procedures and equipment, which will make possible substantial improvements in operational characteristics, such as reliability, range, definition, and suppression of permanent echoes, are in process of development. Semiconductors and low temperature techniques, as well as glass fibre optics, are establishing themselves, and an optical radar, only recently presented to the public, promises well.

Finally, for the electronic processing of radar data, radio techniques should first be thoroughly explored, since the radar operator at his screen is often no longer in a position to to get as much profit from the information furnished as is promised by fully automatic radar techniques. Perhaps digital radar, which converts the incoming data direct into digital form and passes it to an electronic computer for further processing, will provide a solution to this problem.



CSF has developed the SA 417 long-distance radar. Here the antenna on the Paris-Orly control centre building is shown.

The antenna of Cossor's CR787 airport surveillance radar.

Marconi produces this high-performance heightfinding radar, designated S244.

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And now another word about the information compiled on the next two pages. The object which the Editors have set themselves is to present a survey of all types of civil and military radar systems which are in current use or in development. In order to keep this catalogue within bounds, fire control systems and airborne radars have been excluded. Even so, the material is so copious that it has been essential to split up the survey, and the portion of the catalogue published in this issue covers the radar systems produced in Western Europe, insofar as the necessary information is available here in time for press. In order to be able also to include equipment which is nominally subject to military security restrictions, it is necessary to obtain clearance on some of the information, which of course takes time. The next portion of the catalogue, which will appear in a forthcoming issue, will cover primarily radar systems produced in the USA, but will also contain a supplementary list of equipment produced in Europe.

European Radar Systems

Manufacturer	Designation	Application [1]	Wavelength (cm)	Peak Power (kW)	Pulse Length (μs)	Pulse Recurrence Frequency (Mc/s)	Maximum Vertical Coverage (ft)	Horizontal Coverage Reflection Surface 20 m² (n.m.)	Horizontal Coverage Reflection Surface 5 m² (n.m.)	Antenna System [2]	Reflector Dimensions [3] (ft)	Horizontal Beamwidth [3] (degrees)	Aerial Gain [3] (dB)	Polarization [3]	Antenna Rotation Speed (r.p.m.)	Aerial Tilt (degrees)	Remarks
CFTH	TH.D.225	ATC	23	2,000	2/4	500/250	100,000+	150	110	cosec²	39.6×16.5	1.25	34	L/C	6/12		ATI; Frequency diversity; antenna emits two overlapping lobes.
	TH.D.1010	PAR	3	35	0.5	2,000		9.5		independent AZ and EL antennas		AZ:0.6 EL:3.5	AZ:40.5 EL:39	L/C			
	TH.D.1013	PAR (mobile)	3	30	0.5	2,000				ditto	8.25×2.31	AZ:0.8 EL:4.8	35	C	One scan per second		
	RAMSES	Surveillance and navigation radar	3	40	0.15	2,000		Horizon		slotted wave-guide array	7.92 diam.	0.90	30	H	20		
COSSOR	S.S.S.R.4G	Secondary ATC radar	30	Interrogator pulse 0.3-1 Control pulse max. 10	0.85	200-400	All altitudes within range	200				2.5 (interrogation)	25	V	3-15	adjustable	PRF and rotational speed of antenna can be synchronized with primary radar. Double pulse system (ICAO) for suppression of side lobes. If required, can also be delivered for the FAA triple pulse system.
	CR787	ATC (see "Remarks")	10	450	1	700	50,000	90	60	cosec²	6.75×1.33	1.4	30	H/C	12	−2.5 to +2.5	Also utilizable for precision approach path (PPI); MTI.
	CR353	WF/MET	10	800	1/2	300/350	10,000	110-250		paraboloid (see "Remarks")	8 diam.	3	34		auto-following	0-90	Conical polar diagram through asymmetrical dipole.
CSF	SA413	ASR	23	2×2,000 (Diversity)	1.5-2.5/4	700 400/250	70,100	105	82	cosec²	18.15×7.59	2.8	27	H/C	7.5/15	0 to +6	Elimination of blind speeds by PRF wobbulation; double MTI by means of TCM-13 memory tubes.
	SA417	ATC	23	2×2,000 (Diversity)	1.5-2.5/4	700 400/250	85,000	200	155	cosec²	39.6×18.15	1.3	34	H/C	3/6	2.5 to 6.5	Ditto
DECCA RADAR	DASR-1	ATC	10	800 per beam	2	275	40,000	110	75	2 double-curvature reflectors mounted back-to-back	a) 23.33×12.33 (high coverage) b) 23.33×7.67 (low coverage)	0.95	a) 37 b) 39	L/E/C variable	10	a) +2 to +7 b) −1 to +4	ATI; by using travelling wave tubes, detection height and range can be improved by 11 %; each of the two transmitter/receivers can be switched to each antenna.
	DASR-3	ATC	10	2.5 per beam	5	250	60,000+	150+	115+	ditto	a) 23.33×12.22 (high coverage) b) 23.33×7.67 (low coverage)	0.95	a) 36.5 b) 38.5	L/E/C variable	10	a) +2 to +7 b) −1 to +4	ATI; by using travelling wave tubes, detection height and range can be improved by 9%; each of the two transmitter/receivers can be switched to each antenna.
	Type 424 Mk.II 400/250	ASR (see "Remarks")	3	30	0.1/0.5	1,000	4,000	25	15		14	0.6		L/C/E	20-24	−2 to +12	Also suitable for precision approach (PPI).
	HF 200	Height-finding radar	10	2,500	5	200-250	100,000	25-235	25-160	nodding double-curvature reflector	8×35	3 (vertical 0.75)	40	V (C)	max. 6	−3 to +33	Scanning: 60 per minute.
	W.F.1	WF	3	20	0.5/0.25	1,000		55 (max. slant range)		parabolic dish reflector	8 diam.	1	41.5		manual operation		Measurement of high altitude winds by tracking balloon-borne reflectors.
	W.F.2	WF	3	75	0.5/0.25	500		110 (max. slant range)		parabolic dish	8 diam.	1/5	41.5	H	manual operation		Ditto.
	Type 40	Storm warning	3	20	1/0.1	500/1,000		max. 120		double cheese	6	1.2	30	H	10		
	Type 41 Mk.IIA	MET	3	20	2/0.2	200		250		double-curvature parabolic reflector	14	0.6	42.5	H	5-6	−2 to +28	
	Type 32	Harbour radar	3	10	0.5	1,840				parabolic reflector	25×2	0.3	44	H	20		
	Type 34	Harbour radar	3	20	0.05/0.15	2,000				slotted waveguide array	9.5	0.75	33	H	24		
	Type 215	River radar	3	20	0.05/0.15	1,000		max. 6		parabolic cylinder	6	1.2	30	H	24		Relative motion display.
	D.303	Marine radar	3	10	0.1/0.5	1,000		36		parabolic cylinder	4	1.7	27.5	H	20		Relative motion display.
	D.404	Marine radar	3	20	0.1/0.5	1,000		48		parabolic cylinder	6	1.2	30	H	20		Relative motion display.
	D.505	Marine radar	3	75	0.1/0.5	1,000		48		parabolic cylinder	6	1.2	30	H	20		Relative motion display.
	D.535	Marine radar	3	75	0.1/0.5	1,000		48		slotted wave-guide array	10	0.75	33	H	20		Relative motion display.
	D.606	Marine radar	3	20	0.1/0.5	1,000		48		parabolic cylinder	6	1.2	30	H	20		Relative motion display.
	TM.707	Marine radar	3	20	0.1/0.5	1,000		48		parabolic cylinder	6	1.2	30	H	20		True motion display.
	D.808	Marine radar	3	75	0.1/0.5	1,000		48		parabolic cylinder	6	1.2	30	H	20		Relative motion display.
	D.838	Marine radar	3	75	0.1/0.5	1,000		48		slotted wave-guide array	10	0.75	33	H	20		Relative motion display.
	TM.909	Marine radar	3	75	0.1/0.5	1,000		48		parabolic cylinder	6	1.2	30	H	20		True motion display.
	TM.939	Marine radar	3	75	0.1/0.5	1,000		48		slotted wave-guide array	10	0.75	33	H	20		True motion display.
	TM.969	Marine radar	3	75	0.1/0.5	1,000		60		slotted wave-guide array	10	0.75	33	H	20		True motion display.

[1] ATC
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Manufacturer	Designation	Application [1]	Wavelength (cm)	Peak Power (kW)	Pulse Length (μs)	Pulse Recurrence Frequency (Mc/s)	Maximum Vertical Coverage (ft)	Horizontal Coverage Reflection Surface 20 m² (n.m.)	Horizontal Coverage Reflection Surface 5 m² (n.m.)	Antenna System [2]	Reflector Dimensions [3] (ft)	Horizontal Beamwidth [3] (degrees)	Aerial Gain [3] (dB)	Polarization [3]	Antenna Rotation Speed (r.p.m.)	Aerial Tilt (degrees)	Remarks
DECCA RADAR *(continued)*	Type 978	Marine radar	3	40	0.2/1	2,000/1,000		60		double cheese	each 6 × 0.3	1.2		H	24		Also available with B-scope display system.
	TM-S.2400	Marine radar	10	75	0.1/0.5	1,000		60		slotted waveguide array	12	1.9	27.5	V	20		True motion display.
EKCO	CE71	PAR	3	10				16		dish reflector	10 (circular)				manual operation		PAR combined with VHF-DF
FIAR	P33	ASR	10	200	0.55	780	10,000+	32+	22+	cosec²	15.18 × 7.59	1.5	33.8	H	12	+1 to +7	
	P79	PAR (mobile)	3	35	0.25	2,400		10+		2 parabolic reflectors	AZ: 15.8 × 3.3 EL: 1.15 × 15.18	0.58	AZ: 41.5 EL: 40	L/C	1 slew each way per second	AZ: −1 to +6 EL: ±10	Partly under British Thomson Houston licence Under Telefunken licence.
MARCONI	S247	Long-range surveillance radar (military)	a) 10 b) 23	a) 2,250 b) 2,250	a) 2.5-5.5 b) 2.5-5.5	a) 200-550 b) 200-550	100,000	a) 345 b) 234	a) 245 b) 166	a) parabolic cylinder b) modified parabolic profile (back-to-back)	each 45 × 15	a) 0.53 b) 1.25	a) 45 b) 36	H	0-10	−1 to +9	a) Pulse-width discriminator required. b) MTI (Triple Pulse Cancellation). If required the 10 cm and 23 cm systems are available separately.
	S232/2	ASR	50	50-60	2/4	500-800	26,000	95	70	paraboloid	29 × 10	4	27	H	7.5/15	−1 to +10	MTI crystal controlled.
	S264/ S264H	ATC	50	50-60	2/4	500-800	40,000	120	85	parabolic cylinder	52.5 × 12	2.1	31	H	5/10	−1 to +10	MTI crystal controlled; high altitude coverage (over 50,000 ft) can be obtained with the S264H at shorter range (65 to 95 n.m.) by means of a modified antenna.
	S264A/ S264A/H	ATC	50	50-60	3/4	260-400 (3 or 5 μs) 500-550 (3μs)	80,000+	200	150	parabolic cylinder	52.5 × 12	2.1	31	H	5/10	−1 to +10	MTI crystal controlled; high altitude coverage (over 90,000 ft) can be obtained with the S264A/H at shorter range (120 to 170 n.m.) by means of a modified antenna (56.6 × 3 ft).
	S307	ATC	50	500	3/4	260-385 (3 or 4 μs) 500-550 (3 μs)	95,000+	220	170	parabolic cylinder	67.5 × 12	1.7		H	5/10	−1 to +10	MTI crystal controlled.
	S244	Height-finding radar	10	2,250	2.5-5.5	250-310	120,000	240	170	vertical nodding antenna	8 × 40	3.7 (0.6 vertical)	40.5	V		max. 30	Pulse width discriminator.
	SNW51	Storm warning	3	40	2	350		200		parabolic cylinder	13.5 × 3	0.5 (3.8 vertical)	42.4	H	7/10/14/21	−5 to +12	Fixed and mobile versions.
	SNW43/ SNW44	Surveillance radar	3	20	0.1/1.0	1,000/500		30 or 40 (SNW43) 36 or 48 (SNW44)		parabolic cylinder	13.5 × 3	0.5	42.4	H	7/10/14/21	−5 to +12	
	SNW40/ SNW41/ SNW42	Coastal, harbour and airport	3	40	0.2/1.0	2,000/700		40 (SNW40 & SNW42) 45 (SNW41)		parabolic cylinder	13.5 × 3	0.5	42.4	H	7/10/14/21	−5 to +12	
	S314	Coastal defence	10	800	0.5/2.5	1,000/500				paraboloid	29 × 10	0.75	44.9	H	0.5-10	−2 to +9	Suitable for unattended operation.
	NR502 /1 & NR502/2	Marine radar	3	50	0.2/1.4	2,000/500		40		paraboloid	5.08 × 1.33	1.5	32	H	25	0	
	NR505	Marine radar (see "Remarks")	3	2.5	0.15/0.6	2,000		30 yd-14 n.m.		slotted waveguide array enclosed in radome	3 × 0.45	2.6	29	V	22	0	Very small dimensions; also works off battery.
SELENIA	ATCR-2	ATC	23	2,500	2	360	210,000	148	105	cosec²	44 × 10	1.25	33	H/C	4.5/9	−1 to +4.4	MTI
	NR503 & NR504/1	Marine radar	3	20	0.1/1.0	1,000/500		NR503: 75 ft-40 n.m. NR504: 90 ft-48 n.m.		paraboloid	5 × 1.32	1.5	32	H	25	0	
	Meteor 200 Type RMT-1c	MET	3	200	0.5/3	1,200/200		70-250		paraboloid	4.62 diam.	1.6	40	V	5	−10 to +90	Similar types: RMT-2a and RMT-3a.
	JASON 40X Type RNS-103	Navigation and surface search	3	40+				15		slotted waveguide array	8.6 × 2	0.9	30	H	24		
SFIM	MESTA 102	Traffic radar	3	10 mW	CW			165 yd	110 yd	slotted waveguide array		4	23	V	fixed antenna		
	MESTA 120	Traffic radar	3	50 mW	CW			1,650 yd	1,100 yd	paraboloid	1.33	6	24	V	fixed antenna		
STC	SLA.3	PAR	3	40-60	0.18-0.25	3,825		8.5		Dipole array; fed by variable width waveguide	14 × 1.75	AZ:0.5 EL:4.0	42.5	AZ: H (C) EL: V (C)	2 scans per antenna per second	adjustable by remote control	
TELEFUNKEN	ASR-3/2	ASR	10	500	1	1,200	33,000	55	38	cosec²	12.87 × 11.22	1.8	32	V/H C/E	16/24	−2 to +7	MTI.
	ASR-B	ASR (mobile)	10	500	1	1,200	33,000	60	35	cosec²	17.16 × 7.59	1.35	33	V(H)/C	12/24	−2 to +7	Whole system transportable on two vehicles.
	ASR-4	ASR	10	500	1	1,070	33,000	55	38	cosec²	12.87 × 11.22	1.8	32.5	V/H/C	12/16/24	−2 to +7	Double MTI with velocity shaping; PRF staggering; produced as secondary radar.
	M 3100	ATC	23	1,000	2	500	70,000	230	165	cosec²	47.85 × 23.1	1.05	38.5	V/H(C)	6(4)	−2 to +6	MTI.
	PAR-2	PAR	3	100	0.25	2,400		10		mechanically operated 2PT antenna	15.18 × 3.3 2.14 × 15.18	AZ: 0.58 EL: 3.4	AZ: 41.5 EL: 40	AC: V(C) EL: H(C)	1 slew each way per second	AZ: −1 to +6 EL: ±10	Slewable in six different approach directions by remote control.
	PAR-C	PAR (mobile)	3	35	0.25	2,400		10		mechanically operated AZ and EL antenna	AZ: 15.18 × 3.3 EL: 2.14 × 15.18	AZ: 0.58 EL: 3.5	AZ: 41.5	AC: V(C) EL: H(C)	1 slew each way per second	AZ: −1 to +6 EL: ±10	Whole system transportable on two vehicles.

[1] ATC—air traffic control; PAR—precision approach radar; WF—wind finding; MET—weather radar; ASR—airport surveillance radar (ATC). [2] AZ—Azimuth; EL—Elevation. [3] C—Circular; E—Elliptical; H—Horizontal; L—Linear; V—Vertical.

Problems of all-weather automatic landing

by Dr. J. Goerner, Bell Aerosystems Company, Buffalo, New York

The need for all-weather automatic landing is now fully recognized and emphasized by both civil and military aviation. Present revenue losses of the airlines because of foul weather run to about $25,000,000 annually in the United States. Independence of weather is equally important for military aircraft, since a cancelled mission may result in loss of a battle. The very rapidly increasing business aircraft fleet, with more than 35,000 aircraft in the United States, presents another problem, since they also require service by a system, at least to the extent of drastically reducing the present approach limits.

Weather limitations are only one aspect of the problem. Flight-safety considerations are also an equally important factor. It is well known that most flight hazards are concentrated during the short approach and landing interval. In 1960, 31 percent of all the accidents to civil transport aircraft in the western world occurred during this phase.

Although there is agreement on the broad general goal of operating into and out of an airport regardless of ceiling and visibility, specifications of the system's operational requirement have not yet been established nationally or internationally. This is not surprising in view of the complex technical and operational factors involved. Correspondingly, the attack on the problem has proceeded—and still does—along different avenues, each one emphasizing particular areas of the overall problem.

Doubt exists whether the specifications for a common system could be generated at the present time without more operational experience and data derived from presently available systems. Nevertheless, it is useful and necessary to consider critically the technical, operational and evolutionary problems which should be taken into consideration. Though admittedly the various points discussed in this paper require additions and modifications, it is felt that they may serve as an aid in defining an idealized system as a yardstick. No practical system, of course, will meet all requirements, but the degree of approach to the ideal should provide a basis for selection.

Technical Functions

Any automatic landing system has to measure the aircraft's position (e.g., altitude, lateral deviation from runway centerline, distance to touchdown). In addition, it has to determine the aircraft's velocity vectors (e.g., sink rate, cross-track rate, range rate) either by direct measurement or by differentiating the position information. Based on this information, a computer must generate appropriate steering commands for the autopilot, in order to land at the intended point with the desired impact sink rate. The system is classified as " air-derived " or " ground-derived ", depending on whether the bulk of the hardware for measuring and computing is airborne or located on the ground. In addition, either system type may employ a fixed path computer or a terminal condition computer. Fixed path computers cause the aircraft to fly a specific, although adjustable, flight path, while the terminal computers recompute, at any instant after a disturbance, a new flight path terminating at the intended touchdown point with the desired slope.

Each design philosophy — air-derived versus ground-derived and fixed versus recomputed flight path—has its pros and cons. There is practically no difference in the touchdown results between fixed path and recomputing path techniques. The performance limits in either scheme are basically dictated by the characteristics of the aircraft/autopilot combination. The categorizing into air-derived and ground-derived versions is somewhat artificial, and the dividing line is vague. Any practical system needs some ground installation for the determination of the aircraft's position. A natural reference, the earth's surface, exists only for altitude; and even this reference is a limited one due to the varying topography of the terrain. The choice should, therefore, be based on the merits of the systems with respect to operational, economic and evolutionary implementation aspects. It should, however, be pointed out that the special case of automatic landing on aircraft carriers practically demands a ship-based computer, since the motion of the deck has to be taken into account.

Immediately before touchdown, the aircraft must decrab to reduce the lateral load on the landing gear. The problems associated with decrabbing an aircraft are the same for all automatic landing systems. The instant of decrab initiation must be chosen so that enough time remains prior to touchdown to align the aircraft with the runway direction. On the other hand, the time until touchdown must be sufficiently short to avoid excessive lateral translation due to the aerodynamic side force acting on the aircraft after decrabbing. Further, the wings must be kept horizontal during the decrab maneuver. It is comparatively easy for any landing system computer to determine the proper instant of decrab initiation from accurate altitude and sink rate information. The decrab maneuver may then be executed either manually by the pilot or automatically by the autopilot. The autopilot configuration for this task depends on the aircraft's characteristics, especially the magnitude of the induced roll moments due to yaw maneuvers. The technical problems of automatic decrab can be mastered. For the present, the additional cost of retrofitting aircraft autopilots to perform the decrab maneuver automatically may not be warranted.

What has been said for automatic decrab is even more true for full automatic rollout. To perform complete automatic rollout, an entirely new control system is needed in the aircraft, since control of the nose wheel and the brakes is required. Rudder control is only effective as long as the aircraft has sufficient speed. Before introducing full automatic rollout, a solution must be found for the more immediate goal of drastically reducing the approach limits until the airplane can be guided automatically to within a few feet above ground or even to touchdown. It is probable that modern, high-efficiency runway center lighting may provide enough information to make rollout by the pilot possible even under adverse weather conditions.

Operational Aspects

One point which cannot be stressed too strongly is safety. A firm requirement has been established in the United Kingdom by the Air Registration Board. Its reasoning is that the present landing accident rate of 0.65 per 10^6 landings should by no means be worsened due to the introduction of ALS equipment. In fact, the safety should become higher, and a minimum safety figure of one fatal risk per 10^7 landings is suggested. There is reluctance in the United States to establish such a quantitative safety goal, which is not amenable to experimental verification. Different schools of thought exist also with respect to the means of achieving high safety. There is a philosophy that favors redundancy by multiplexing autopilots, sensors, etc., and considers the human pilot as nonexistent. This philosophy is certainly conservative, but it is costly and unsuited for retrofitting of existing aircraft. Moreover, the weight and space penalty due to multiplexing of equipment appears hardly bearable for fighter planes already crammed with electronic gear and for the smaller business aircraft where the weight and cost become prohibitive. Redundancy by complementary systems, independent monitors and use of the human pilot are alternatives worth extensive study. The present accident rate of 0.65 per 10^6 landings shows that the human pilot may be utilized as a very reliable part of the servo loop. Admittedly, however, the most suitable instrumentation and takeover arrangements for effective usage of the human pilot have still to be studied from a human factors standpoint.

Closely related to safety are considerations with regard to monitoring capability, elimination of human errors and maintainability. It is highly desirable to monitor the approach and landing on the ground by means of a simple and clear display, showing azimuth, elevation and range of the aircraft. This could provide both safety monitoring and the basic capability to accomplish precise talkdowns if necessary. If the aircraft leaves a safe approach volume, the pilot should be able to abort the landing when it is aerodynamically possible to do so. The setting of specific parameters (e.g., aircraft type, glide path, etc.) by human operators introduces the possibility of human errors and should be avoided. If this is not possible, a wrong setting must not result in a catastrophic failure.

The benefits of easy maintenance and checking procedures are obvious. Consideration should be given to the fact that ground equipment is continuously and easily accessible while the overhaul, maintenance, and checking out of airborne equipment is essentially restricted to the time the aircraft is grounded.

In addition to the safety aspects, attention must be paid to economic considerations. This touches problems such as integration with the Traffic Control System and compatibility with present feeder systems (e.g. ILS, VOR, VOR-TAC, TACAN, GCA).

In view of the huge investments expended on these installations, it is very desirable to utilize them as feeders. The landing system should, therefore, have capabilities compatible with the minimum range and guidance tolerances of these feeder systems.

Important economic as well as technical points are the weight, space and cost requirements of the airborne equipment and the siting requirements of ground installations. Space and weight, occupied by the airborne equipment, are direct losses for commercial transport and cargo planes. Military aircraft are already overloaded with electronic equipment. The installation of bulky and heavy equipment is prohibitive for the smaller executive airplanes. The cost of airborne equipment for the total number of aircraft serviced, plus the cost of ground installations, should be considered in rating the economy of a particular system.

There are certain other technical features that must be considered. One point of concern is sensor or control system switching during the landing operation. One method may employ the same sensor throughout the operation, and another may utilize a variety of sensors in sequence. In addition, the system may use closed loop control all the time or may operate open loop on stored memory. Clearly, continuous closed loop control and avoidance of sensor switching are most desirable from the standpoint of simplicity and reliability. Another frequently raised question is that of tolerable touchdown-dispersion. In the past, this point has been overemphasized, probably because dispersion can be easily checked and verified. Practical results with the most advanced American and English systems show that a longitudinal dispersion of 250 feet rms and impact sink rate dispersions of one foot per second rms are practical values. The desired mean impact sink rate is usually selected as two feet per second.

Evolutionary Transition from Present Approach Techniques to Full Automatic Landing

Automatic landing cannot be introduced overnight. It will probably require several years of evolutionary transition, starting with lowering the present approach limit and establishing pilots' confidence in automatic approach and landing devices.

Economic considerations make it highly desirable that any new equipment which is introduced to allow lower IFR minimums should have the inherent capabilities for eventual automatic landing. The objective should be reached with a minimum of retrofitting and additional hardware. If it is possible to use present receivers and couplers, it may be also desirable that the system be operated as a substitute for ILS and GCA without the deficiencies of these systems. To allow talkdown to altitudes of 50 feet, the monitor display must be clear, without clutter, and precise to the extent that deviations of a few feet from the desired path are observable. The system should be free of ILS deficiencies, such as beam irregularities, extreme beam gain changes, and siting problems.

A very important element in any automatic landing system is the autopilot. The performance requirements for a fully automatic landing are much more stringent than for an ILS approach. The flare maneuver requires a firm control of the airplane and adequate maneuverability, while the requirement to stabilize the aircraft on a straight line during the ILS approach can be met by an autopilot having relatively sluggish performance and limited maneuverability. However, practical flight experience and analyses, conducted by the Bell Aerosystems Company for many aircraft types and autopilot types, have shown that present autopilots, when suitably modified and well maintained, can perform the flare maneuver. The stipulation of suitably modified and well-maintained autopilots deserves some more explanation.

First, the autopilots are normally adjusted for cruising conditions. For fixed gains, however, the aircraft's response decreases considerably with decreasing speed. The response is, therefore, rather sluggish at the low approach speed unless a built-in compensation device increases the autopilot's gains automatically with decreasing airspeed. Such automatic gain compensation is very helpful and many autopilots have incorporated this feature.

Second, autopilots, especially in commercial aircraft, are adjusted for passenger comfort, and thus are relatively insensitive. Increasing the autopilot's gain is, therefore, usually required for the landing phase. Once the gains are increased properly, the tolerable gain variation due to aging of components, supply voltage variations, etc., is not stringent. Plus and minus 15 percent is tolerable even for touchdown requirements.

Concerning the maintenance of autopilots, a new philosophy appears to be necessary. Experience has shown that autopilots are frequently not maintained as they should be. The reason for this fact is that the autopilot is not yet considered as vital a component as is a radio receiver or an aircraft engine. ◆◆

The Automatic Landing System of Bell Aerosystems Company

Bell Aerosystems Company has demonstrated with its system more than 3,000 automatic landings with a large variety of aircraft, and is manufacturing landing systems for use on aircraft carriers under a contract with the U.S. Navy. A land-based version, built for the Air Force, is now located in Atlantic City, N.J., at the Bureau of Research and Development Center, Federal Aviation Agency.

Like all the other presently proposed landing systems, the Bell system requires a feeder system. It has the capability of accepting aircraft on hand-over from such present navigation aids as GCA, ILS, TACAN and VORTAC. The feeder system has to guide the aircraft in proper sequence to an acquisition window, 10,000 feet wide by 800 feet high, located four nautical miles from touchdown. Once the aircraft flies through this window, a ground-based precision tracking radar locks on automatically and tracks the aircraft until touchdown. The radar determines slant range, azimuth and elevation angles which are converted into rectangular position coordinates, namely horizontal range from the intended touchdown point, altitude and lateral deviations. These position data are fed to a ground-based computer which determines the lateral and vertical errors with respect to a selectable but fixed path (including flare) and generates dynamically correct pitch and bank commands for the aircraft. These commands are sent by means of a data link to the aircraft thus closing the guidance loop.

The radar operates presently with 8.6 millimeter wavelength and has, under adverse weather conditions (rain with an average intensity of 10 millimeters per hour between radar and aircraft) a range of four nautical miles. To utilize the high precision of the tracking radar, a point target in the form of a corner reflector or beacon transponder must be provided on the aircraft.

The bulk of the equipment is located on the ground, thus minimizing the equipment in the aircraft. This is equally significant for military airplanes and small business aircraft where the available space is very limited. The system also provides easy maintainability, convenient tie-in with traffic control, overtake warning, talkdown, monitoring and recording capabilities.

Coupled with these advantages is the disadvantage that three parameters for the aircraft type to be landed have to be set into the ground computer. If this is done manually by the operator, possibility of human error cannot be denied. However, should the incorrect setting result in improper response of the aircraft, the monitor operator can detect this and initiate wave-off. Should the operator overlook such discrepancies and the aircraft leave the safe control volume, the wave-off is initiated automatically. To make the system fully foolproof in this respect, an automatic interrogation of the aircraft as to its type may be employed. This feature is incorporated in the Navy system now being fabricated.

The installation of the radar is independent of topography. Vertical and lateral guidance signals are derived from a single source and no transition phases exist. Once the aircraft has been taken under control, continuous closed loop guidance is provided until touchdown.

A special feature of this system is its backup modes. Should the autopilot fail, the system is capable of operation in a mode similar to conventional ILS, allowing the pilot to approach manually using the cockpit display. Should the data link fail, the system is capable of operation in a mode similar to GCA, whereby the pilot is talked down.

Book Reviews

Mechanics of Materials. — By Archie Higdon, Edward H. Ohlsen and William B. Stiles. John Wiley & Sons, Inc., New York & London, 1960 (English; 502 pages with numerous illustrations; price $7.75).

Even at a rapid glance, the number of illustrations is striking. As university professors, the authors are fully aware of the difficulties involved in presenting their subject, and have therefore spared no effort to assist the student with clear drawings and a number of problems for solution. The book is divided into the following sections: centric loading, torsional loading, flexural loading (stresses and deflections), statically indeterminate beams, combined loading, columns, repeated loading, dynamic loading, connections.

As the work is designed primarily for practical application, mathematical formulae are limited to basic essentials. Nevertheless, a knowledge of differential and integral calculus is essential for an understanding of the subject matter. Pr.

Spitfire—The Story of a famous Fighter. — Compiled and written by Bruce Robertson. — Harleyford Publications Ltd., Letchworth, England, 1960 (English; 211 pages with numerous photographs and 30 three-view drawings; price 45s.).

This book is a comprehensive record of the development of the *Spitfire* from the Schneider Trophy seaplanes to the *Seafire*, *Spiteful* and *Seafang* variants.

The contents of the work are divided into three sections. Part I deals with the history of the aircraft and the events leading up to appearance of the first prototype, the war years, and finally the post-war activities of the aircraft. Part II contains a record of the production and service data, while Part III consists of a review of Marks and variants.

Perhaps this is the most comprehensive record of any single aircraft that has been published until now. Every role which the Spitfire fulfilled is dealt with, and the book represents an accumulation of over 25 years' record keeping. Detailed analysis is the keynote of the work and it is possible that this book will become the standard work of reference on *Spitfire* history.

Books Received

Scientific and Technical Publications of the Ministère de l'Air. — Issued by the Service de Documentation et d'Information Technique de l'Aéronautique, Paris, 1960-1961.

No. 358: Problèmes de la surface portante annulaire traités par la méthode des analogies rhéoélectriques, by Gérard Hacques.

No. 363: Sur l'influence de l'accélération sur la résistance au mouvement dans les fluides, by J. L. Luneau.

No. 364: Etude expérimentale des ondes de choc produites par décharges d'un condensateur dans un tube à gaz, by Roger Der Agobian.

No. 365: Application des décharges électriques à l'exploration des écoulements gazeux aux grandes vitesses, by Pierre Couvertier.

No. 366: Détermination par la « méthode inverse » des caractéristiques des ondes explosives, by N. Manson.

No. 367: Mise en œuvre d'un procédé de détermination expérimentale du domaine transsonique dans un écoulement de type mixte, by Gérard Gontier.

No. 368: Equations intrinsèques du mouvement à trois dimensions des fluides à viscosité, by François-Joseph Bourrières.

No. 369: Etude de l'écoulement d'un fluide dans un tunnel prismatique de section trapézoïdale, by Emile Rodet.

No. 370: Contribution à la détermination des limites d'inflammabilité des hydrocarbures, by Nicolas Sivolobov.

No. 371: Chronophotographie électronique. Application à l'étude des phénomènes aérodynamiques évolutifs, by Billes Batailler.

No. 372: Contribution à l'étude du rendement d'une turbomachine axiale à fluide incompressible, by R. Comolet.

No. 373: Les effets secondaires de jet d'un engin autopropulsé, by P. Girardin and F. Tesson.

No. 374: Contribution à l'étude aérothermique d'un jet plan évoluant en présence d'une paroi, by Jean Mathieu.

No. N.T.87: Sur la stabilité des solutions colloïdales en présence d'électrolytes, by Ginette Watelle-Marion.

No. N.T.88: Etude du processus de germination dans la réaction de l'oxygène sur le cuivre aux températures élevées, by Finn Gronlund.

No. N.T.89: Relation entre la structure chimique et la réactivité des combustibles pour fusées à l'acide azotique—constantes physiques des combustions, by Jacques Françon.

No. N.T.90: L'essai de microdureté et ses applications, by H. Bückle.

No. N.T.91: Recherches sur les propriétés optiques des carbures aromatiques, by Alenouch Téryan.

No. N.T.92: Etude des spins et parités de niveaux excités de noyaux par des méthodes d'orientation aux basses températures, de corrélations angulaires et de corrélations direction-polarisation, by Jean-Jacques Perez y Jorba.

No. N.T.93: Contribution à la chimie des solutions aqueuses de titane tétravalent, by Claude J. Garrigues.

No. N.T.94: Etude expérimentale de la convection de la chaleur dans un canal avec profils de vitesse variables, by J. J. C. Picot.

No. B.S.T.125: Sur le calcul des grilles de profils, by André Papon.

No. B.S.T.126: Théorie du calcul des cercles, by G. Czerwenka.

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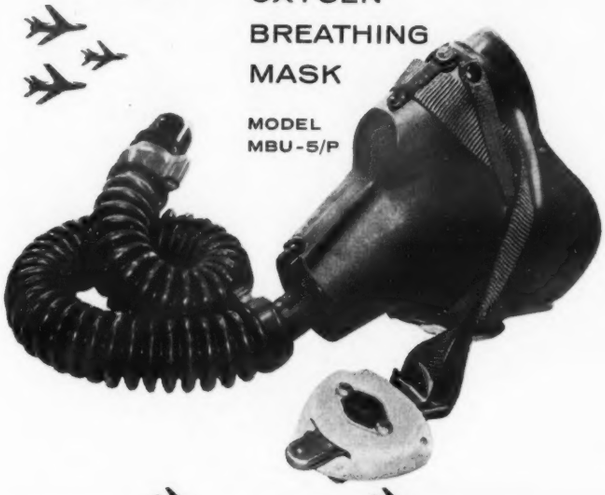

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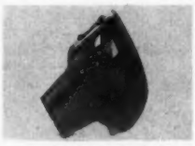

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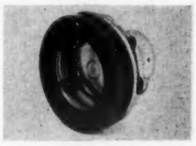

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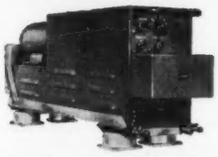

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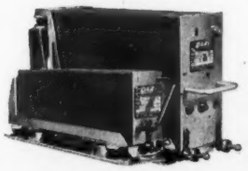

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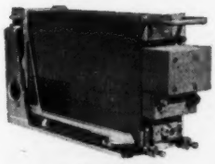

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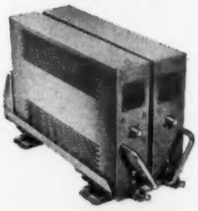
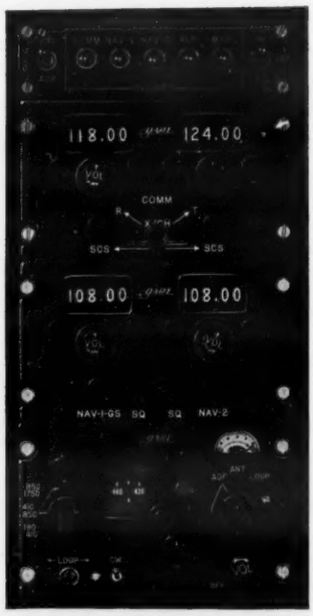


DGS-20—Glide Slope Navigation Receiver

DM-3—Marker Beacon Navigation Receiver



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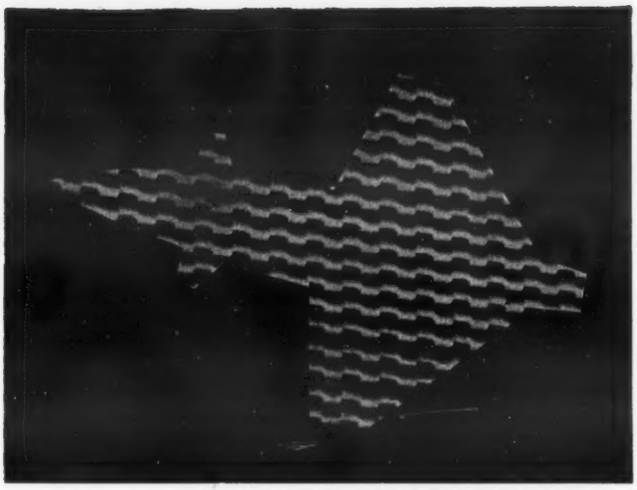

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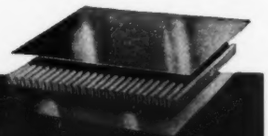

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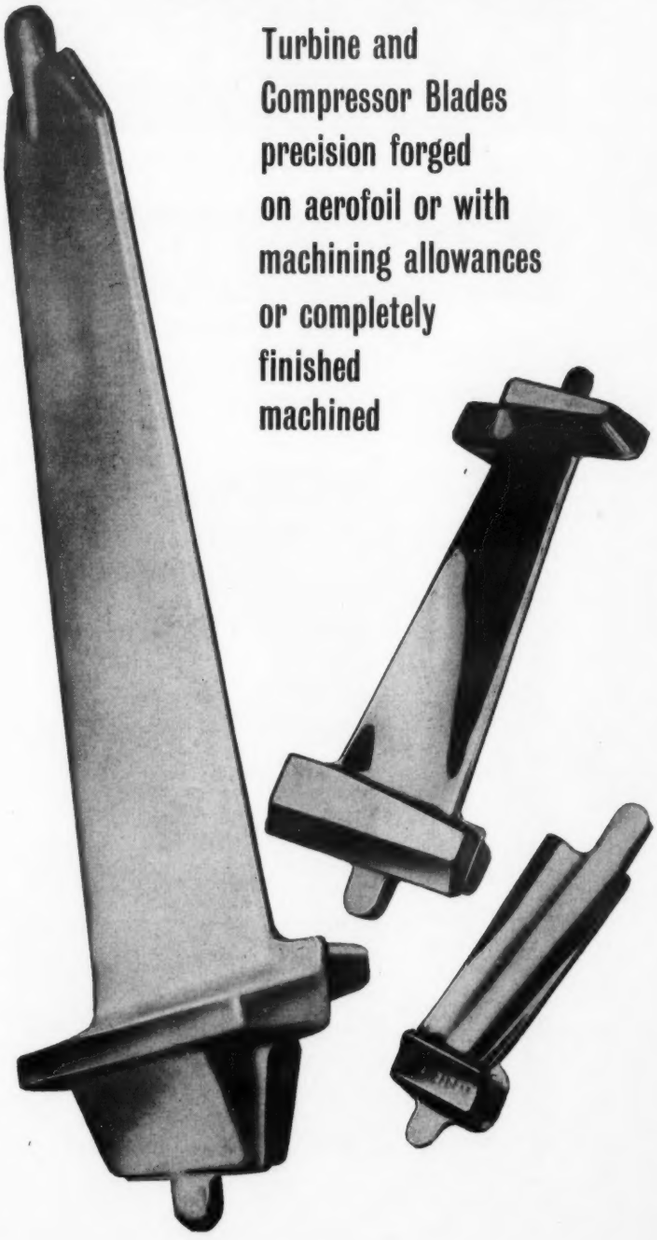

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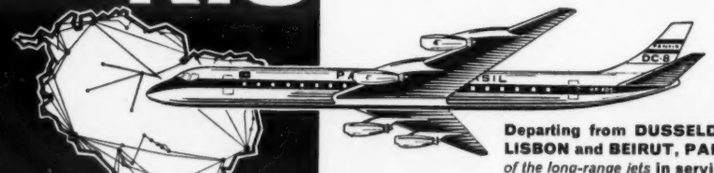

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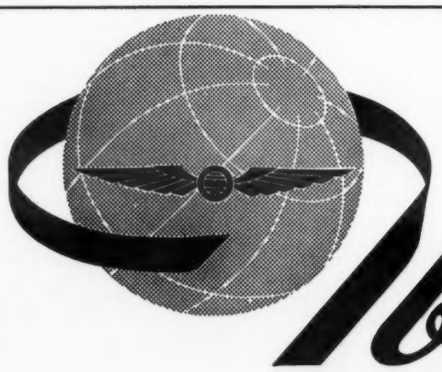

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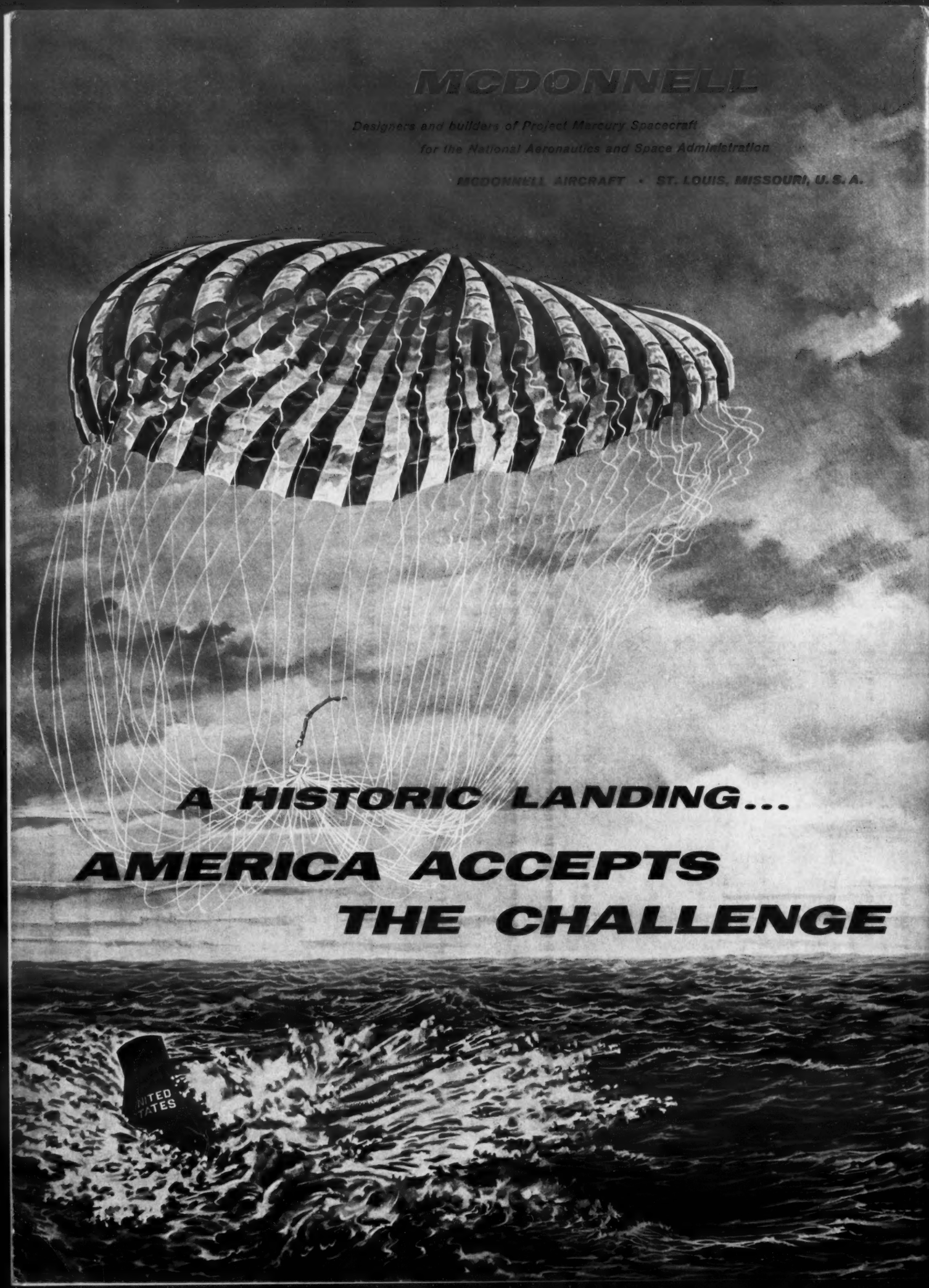
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